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THE RELATIONS BETWEEN FREE-AIR TEMPERATURES AND WIND DIRECTIONS.*

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SYNOPSIS.

All available data from kite flights made during the period 1915 to 1922, inclusive, have been considered. The investigation has been pursued along the following lines: (1) The temperatures at different heights have been classified according to surface wind direction; (2) the temperatures at 3 kilometers have been classified according to wind direction at that level; and (3) changes in temperature at 3 kilometers, as observed during series of successive kite flights extending over periods of several hours, have been examined individually in connection with the wind direction or with changes in the wind direction. It is found (*a*) that in a large majority of cases the relation between temperatures and wind directions is direct and appreciable, south component winds being considerably warmer than north component winds at all levels in the troposphere; (*b*) that the relation is more pronounced at 1 and 2 kilometers than it is at greater heights or at the surface; and (*c*) that exceptions to (*a*) are due either to a temporary reversal in the latitudinal distribution of temperature or to the fact that the wind direction in some instances does not represent the true source of the air, the latter having followed a curved path round a HIGH or LOW.

INTRODUCTION.

The relation between free-air temperature and wind has in recent years been the subject of considerable discussion and some controversy. There are those who hold that the wind direction exercises practically no influence upon the temperature;[1] others, that the relation is the reverse of that at the surface, or in other words that a north-component wind is accompanied by rising temperature and vice versa;[2] and still others, that the normal and most frequent condition is a lower temperature with wind from a northerly than with wind from a southerly quarter, or, what amounts essentially to the same thing, as will be explained later, a lower temperature with rising than with falling barometric pressure.

The purpose of the present paper is to bring to the discussion of this subject such additional information as is now available as the result of a large number of free-air observations made in the United States from 1915 up to the present time. The study has been pursued along the following lines: (1) The temperatures at different heights have been classified according to surface wind direction; (2) the temperatures at 3 kilometers have been classified according to wind direction at that level; and (3) changes in temperature at 3 kilometers, as observed during series of successive kite flights extending over periods of several hours, have been examined individually in connection with the wind direction or with changes in the wind direction.

1. FREE-AIR TEMPERATURES AND SURFACE WIND DIRECTIONS.

In this part of the study all observations made with kites at stations that have been in operation since 1915 have been considered, and the same general characteristics are apparent in all cases. However, the discussion is confined chiefly to data from Drexel, Nebr., and Ellendale, N. Dak., because of the greater length of record at those stations and therefore the greater dependability of the results. Table 1 contains the number of observations at selected levels for the 16 wind directions. There is about equal distribution among the 4 seasons. All directions are well represented except ENE. to ESE. in the higher levels. At the bottom of the table is given the number of observations with NNW. to NNE. and SSE. to SSW. winds, i. e., with distinctly north and south components, respectively.

Table 1.—*Number of observations on which are based the results given in Tables 2, 3, 4, and 6, and in Figure 2.*

Surface wind direction.	Altitude above M. S. L. (meters).									
	Drexel, Nebr.					Ellendale, N. Dak.				
	396	1,000	2,000	3,000	4,000	444	1,000	2,000	3,000	4,000
N	178	173	128	84	21	124	120	68	34	11
NNE	101	96	55	23	6	90	88	42	22	4
NE	101	94	60	30	10	61	57	24	10	3
ENE	65	61	36	17	4	45	42	23	10	1
E	61	59	36	19	3	28	25	16	7	3
ESE	68	65	36	19	5	47	45	31	14	3
SE	121	115	91	58	17	59	57	48	24	2
SSE	202	201	163	103	22	82	81	63	35	10
S	237	231	196	120	39	167	162	131	70	25
SSW	232	229	198	146	53	106	106	85	53	23
SW	134	132	122	92	28	43	43	36	22	4
WSW	84	80	68	55	21	39	39	35	25	12
W	75	74	67	52	14	76	75	69	44	14
WNW	74	74	64	46	15	85	82	75	49	18
NW	148	146	130	97	20	153	150	117	76	25
NNW	212	206	170	103	30	112	110	86	34	15
Total	2,093	2,036	1,620	1,064	308	1,317	1,282	949	529	173
NNW.-NNE	491	475	353	210	57	326	318	196	90	30
SSE.-SSW	671	661	557	369	114	355	349	279	158	58

Observed values of temperature at selected levels have been averaged for each surface wind direction and for each season and the year, and these averages have been smoothed by the well-known process $\frac{a+2b+c}{4}$, in which a, b, and c represent values corresponding to successive wind directions. The results are given in

[1] Dines, W. H.: The characteristics of the free atmosphere. *Geophysical Memoirs, No. 13.* Meteorological Office, London, 1919, p. 66.

[2] Clough, H. W.: The sequence of the interdiurnal changes in wind direction, pressure and temperature in the free air. Abstract in *Bulletin of the American Meteorological Society,* 1922, p. 114.

[3] Blair, Wm. R.: Free-air data. Sounding balloon accensions at Indianapolis, Omaha, and Huron. *Bulletin of the Mount Weather Observatory.* Vol. 4, pt. 4, pp. 192-193. 1912.

Meisinger, C. LeRoy: The preparation and significance of free-air-pressure maps for the central and eastern United States. Mo. Weather Rev. Supplement No. 21, pp. 19-20. 1922.

Gregg, W. R.: Vertical temperature distribution in the lowest 5 kilometers of cyclones and anticyclones. Mo. Weather Rev., September, 1919. 47: 647-649.

* Presented before American Meteorological Society at Cincinnati, Ohio, Dec. 29, 1923, and Philosophical Society of Washington, Feb. 23, 1924.

Table 2. Highest and lowest temperatures at each level are indicated by bold face and italic type respectively, and the difference between these values is given at the bottom of each section of the table.

TABLE 2.—*Mean temperatures, (°C.), at various heights corresponding to surface wind direction.*

SPRING.

Surface wind direction.	Altitude above M. S. L. (meters).									
	Drexel, Nebr.					Ellendale, N. Dak.				
	396	1,000	2,000	3,000	4,000	444	1,000	2,000	3,000	4,000
N	*6.2*	*1.9*	−1.1	−5.7	*−11.4*	1.7	−1.2	−3.9	−8.4	−13.6
NNE	6.5	2.4	−0.4	−5.1	−10.6	3.2	0.5	−2.0	−6.0	−11.1
NE	7.6	3.7	0.8	−4.0	−9.2	5.4	3.1	0.2	−3.5	−8.3
ENE	8.3	5.0	2.2	−2.6	−8.5	7.4	4.9	1.0	−3.2	−7.2
E	8.7	5.8	3.4	−1.8	−9.5	**9.7**	6.8	2.0	−4.1	−7.0
ESE	9.6	7.0	4.0	−1.3	−9.6	**9.7**	6.8	2.5	−4.6	−6.9
SE	10.8	8.3	4.6	−0.8	−8.5	9.2	6.2	2.4	−3.5	**−6.8**
SSE	12.5	10.0	5.7	−0.1	−7.4	9.4	6.8	**2.8**	**−2.2**	−7.0
S	13.8	11.0	**6.4**	**0.4**	**−6.4**	8.8	**7.4**	**2.8**	−2.7	−8.3
SSW	**14.0**	**11.1**	6.1	0.0	**−6.4**	7.4	**7.4**	2.3	−3.8	−10.4
SW	12.8	10.3	4.7	−1.7	−7.8	6.5	6.9	1.8	−4.4	−11.6
WSW	*11.0*	9.0	*3.1*	−3.4	−9.4	7.3	6.5	0.7	−6.1	−12.5
W	10.4	7.4	1.7	−4.5	−10.0	8.3	5.8	−0.8	−7.8	−13.6
WNW	8.6	4.4	−0.8	−6.6	−11.0	5.3	2.2	−3.6	−9.8	−15.2
NW	6.7	2.4	*−1.9*	*−7.2*	−11.2	1.4	*−1.8*	*−6.0*	*−11.1*	*−16.3*
NNW	*6.2*	2.0	−1.5	−6.2	−11.1	*1.3*	*−1.8*	−5.2	−9.9	−15.2
Max.-Min.	7.8	9.2	8.3	7.6	5.0	8.4	9.2	8.8	8.9	9.5

SUMMER.

Surface wind direction.	396	1,000	2,000	3,000	4,000	444	1,000	2,000	3,000	4,000
N	21.0	16.9	11.9	6.5	0.6	18.7	*14.9*	10.5	5.4	0.2
NNE	*20.8*	17.1	12.2	6.5	0.8	18.3	15.3	11.5	6.6	2.0
NE	21.4	17.8	13.2	7.4	1.2	*18.0*	15.8	11.5	6.8	2.2
ENE	21.7	18.2	13.8	7.9	0.8	*18.0*	16.0	11.4	6.8	1.3
E	21.4	18.4	13.8	7.3	−0.9	19.4	16.8	11.6	7.1	0.7
ESE	21.5	18.9	14.0	7.6	−1.0	21.3	18.0	12.6	7.6	0.8
SE	22.4	19.8	14.5	8.0	0.3	22.6	19.0	13.8	8.4	1.4
SSE	23.7	20.8	14.9	8.2	1.1	**22.9**	19.8	14.7	**8.8**	**1.6**
S	25.0	21.8	15.6	**8.6**	**1.7**	22.6	**20.3**	**14.8**	7.8	0.4
SSW	**25.6**	**22.6**	16.1	**8.6**	1.6	21.7	20.2	14.2	6.4	−1.4
SW	25.2	**22.6**	**16.2**	8.4	1.0	20.1	19.3	13.2	5.5	*−1.8*
WSW	24.2	22.2	15.8	8.3	0.5	19.3	18.0	12.0	4.8	−1.3
W	22.9	20.7	14.1	7.1	−0.2	19.2	16.8	10.3	4.1	−1.2
WNW	21.4	18.3	11.5	4.8	−1.4	19.4	16.2	9.5	3.8	−1.4
NW	20.9	*16.8*	*10.0*	*3.8*	*−2.0*	19.5	15.7	*9.4*	*3.7*	−1.3
NNW	21.4	16.9	10.9	5.2	−0.8	19.2	15.0	*9.4*	4.1	−1.2
Max.-Min.	4.8	5.8	6.2	4.8	3.7	4.9	5.4	5.4	5.1	3.4

AUTUMN.

Surface wind direction.	396	1,000	2,000	3,000	4,000	444	1,000	2,000	3,000	4,000
N	6.2	3.5	0.8	−3.9	−8.8	*1.5*	0.1	−1.7	−6.0	−11.6
NNE	7.5	5.3	2.7	−2.8	−8.4	4.4	3.5	1.7	−2.4	−8.1
NE	10.1	8.4	5.4	0.2	−5.9	8.3	7.1	4.5	−0.2	−7.0
ENE	12.1	11.2	7.3	2.2	−3.4	9.4	8.5	5.3	0.0	−8.2
E	12.3	11.7	7.8	1.8	−2.0	7.6	7.4	4.7	−1.4	−9.3
ESE	13.8	12.4	8.8	2.6	−1.4	7.0	6.1	4.6	−1.6	−8.3
SE	**15.4**	13.6	9.9	3.7	−2.1	8.6	7.3	6.1	0.6	−6.4
SSE	15.2	**13.9**	**10.2**	3.8	−2.9	**9.8**	9.7	**7.8**	**2.0**	**−5.1**
S	14.8	13.6	10.0	**3.9**	−2.8	8.3	**9.8**	6.9	1.0	−5.5
SSW	13.3	12.6	8.6	2.8	−3.2	7.0	8.6	4.7	−1.5	−7.1
SW	12.0	11.7	6.8	0.8	−4.6	7.8	8.4	3.5	−3.1	−7.8
WSW	11.9	11.6	5.7	−0.7	−6.0	8.1	8.0	2.8	−3.4	−7.8
W	10.2	9.2	3.6	−2.6	−7.2	8.1	7.0	2.0	−3.7	−8.8
WNW	7.6	5.6	1.3	−4.1	−8.9	6.8	4.6	0.1	−5.2	−11.1
NW	6.3	3.4	0.0	*−4.8*	*−9.8*	4.1	1.4	−2.4	−7.5	−13.4
NNW	*5.8*	*2.6*	*−0.3*	−4.6	−9.3	1.6	*−0.7*	*−3.5*	*−8.4*	*−14.0*
Max.-Min.	9.6	11.3	10.5	8.5	8.4	8.3	10.5	11.3	10.4	8.9

WINTER.

Surface wind direction.	396	1,000	2,000	3,000	4,000	444	1,000	2,000	3,000	4,000
N	−7.7	−8.9	−7.6	−11.2	−17.3	−11.7	−10.8	−9.6	−13.1	−18.1
NNE	−7.0	−7.2	−5.8	−9.0	−16.3	*−12.8*	−11.0	−8.8	−12.2	−16.6
NE	−7.3	−7.0	−5.8	−9.3	−15.0	−11.1	−9.5	−8.0	−10.8	−16.1
ENE	−5.9	−4.9	−4.4	−8.7	−12.5	−7.6	−6.2	−6.2	−8.8	−15.6
E	−3.2	−1.0	−1.8	−6.6	−11.2	−7.1	−5.4	−4.0	−8.0	−15.1
ESE	−2.5	0.0	−1.5	−6.2	−11.8	−8.1	−6.8	**−3.0**	**−8.0**	−14.8
SE	−3.2	−0.8	−1.7	−6.1	−11.4	−8.0	−7.6	−3.1	−8.0	−14.5
SSE	−3.5	−1.2	−1.0	−5.6	−10.7	−7.9	−6.3	−3.1	−8.2	**−14.3**
S	−3.0	−0.3	0.0	−5.0	−10.2	−8.6	−3.6	−3.4	−9.0	−14.6
SSW	−1.6	2.3	**1.0**	**−4.2**	**−9.7**	−7.7	−1.5	−3.6	−9.6	−15.3
SW	−0.5	**3.7**	0.7	−5.0	−10.5	−5.2	**−0.3**	−3.9	−10.2	−16.0
WSW	**−0.4**	2.7	−1.[illegible]	−6.9	−12.0	**−4.4**	−1.7	−5.9	−11.8	−17.5
W	−1.6	0.0	−3.7	−8.8	−14.2	−4.4	−3.8	−7.5	−13.0	−19.0
WNW	−4.0	−3.9	−6.[illegible]	−11.0	−16.5	−6.1	−6.6	−9.1	−14.3	−20.0
NW	−6.6	−7.7	−8.9	−12.9	−17.8	−9.8	−10.7	*−11.8*	*−16.4*	*−21.6*
NNW	*−8.1*	*−9.8*	*−9.5*	*−13.2*	*−18.1*	−11.3	*−11.6*	−11.6	−15.6	−20.8
Max.-Min.	7.7	13.5	10.5	9.0	8.4	8.4	11.3	8.8	8.4	7.3

TABLE 2.—*Mean temperatures, (°C.), at various heights corresponding to surface wind direction*—Continued.

ANNUAL.

Surface wind direction.	Altitude above M. S. L. (meters).									
	Drexel, Nebr.					Ellendale, N. Dak.				
	396	1,000	2,000	3,000	4,000	444	1,000	2,000	3,000	4,000
N	6.4	3.4	1.0	−3.6	−9.2	*2.6*	0.8	−1.2	−5.5	−10.8
NNE	7.0	4.4	2.2	−2.6	−8.6	3.3	2.1	0.6	−3.5	−8.4
NE	8.0	5.7	3.4	−1.4	−7.5	5.2	4.1	2.0	−1.9	−7.3
ENE	9.0	7.4	4.7	−0.3	−5.9	6.8	5.8	2.9	−1.3	−7.4
E	9.8	8.7	5.8	0.2	−5.9	7.4	6.4	3.6	−1.6	−7.7
ESE	10.6	9.6	6.3	0.7	−6.0	7.5	6.0	4.2	−1.6	−7.3
SE	11.4	10.2	6.8	1.2	−5.4	8.1	6.2	4.8	−0.6	−6.6
SSE	12.0	10.9	7.4	1.6	−5.0	**8.6**	7.5	**5.6**	**0.1**	**−6.2**
S	12.6	11.5	**8.0**	**2.0**	**−4.4**	7.8	8.5	5.3	−0.7	−7.0
SSW	**12.8**	**12.2**	**8.0**	1.8	**−4.4**	7.1	**8.7**	4.4	−2.1	−8.6
SW	12.4	12.1	7.1	0.6	−5.5	7.3	8.6	3.6	−3.0	−9.3
WSW	11.7	11.4	5.8	−0.7	−6.7	7.6	7.7	2.4	−4.1	−9.8
W	10.5	9.3	3.9	−2.2	−7.9	7.8	6.4	1.0	−5.1	−10.6
WNW	8.4	6.1	1.4	−4.2	−9.4	6.4	4.1	−0.8	−6.4	−11.9
NW	6.8	3.7	*−0.2*	*−5.3*	*−10.2*	3.8	1.2	*−2.7*	*−7.8*	*−13.2*
NNW	*6.3*	*2.9*	−0.1	−4.7	−9.8	2.7	*0.2*	*−2.7*	−7.4	−12.8
Max.-Min.	5.5	9.3	8.2	7.3	7.8	6.0	8.5	8.3	7.9	7.0

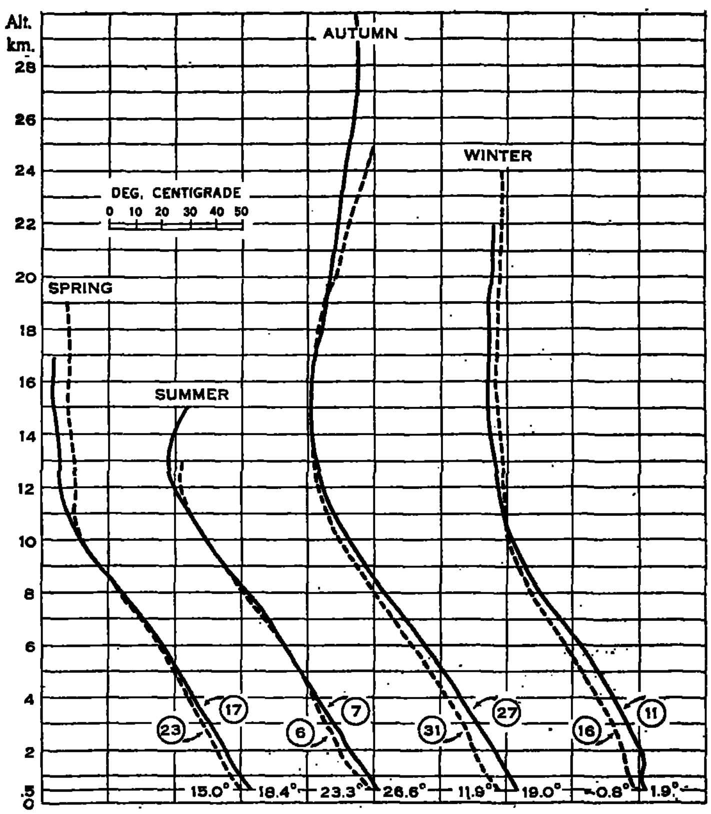

FIG. 1.—Mean temperatures over falling sea level air pressure (solid lines) and over rising sea level air pressure (broken lines); or, with south and north component winds, respectively. (Numbers in circles indicate number of observations upon which curves are based.)

A mere glance at the values in this table shows that at all levels up to at least 4 kilometers much higher temperatures prevail with south component than with north component surface winds. Essentially the same characteristics are apparent in the four seasons, viz, highest temperatures with SE. to SW. winds and lowest with NW. to N. winds. Differences are smallest in summer, averaging about 5° C.; in the other three seasons, among which there is little variation, they average 9° to 10°C. In all seasons they are greatest at 1 and 2 kilometers, but at 4 kilometers they are still sufficiently large, 7° to 8° C., to indicate a continuance of this relation to the upper limits of the troposphere. This conclusion finds support in the results of a large number of sounding balloon observations made in this country. In discussing these, Blair [4] states that lower temperatures are found at all levels in the troposphere with rising than with falling air pressure at the surface, conditions which are accompanied by north-component and south-component winds, respectively. The reverse relation exists in the stratosphere in part because, as is well known, in this region there is an increase, instead of a decrease, in temperature with latitude; in part also because the warmer northward moving air, being the less dense of the two, would cause a vertical displacement of air in the stratosphere upward, a process that would result in more or less cooling of the latter. The curves showing these relations are based upon Figure 33 in Blair's paper and are here presented in Figure 1.

More detailed examination of the values in Table 2 brings out the fact that the change in temperatures from northerly to southerly winds is quite uniformly progressive. This is true for all seasons and for all stations. It is well shown in Figure 2, which gives the temperature distribution with surface wind direction at Drexel from the surface to the 4-kilometer level. It is interesting to note that at all heights the sharpest change occurs between SW. and NW. winds, temperatures accompanying W. winds being almost exactly halfway between these two in the upper levels. This large difference is presumably due in part to the greater average speed of these winds than of winds from other directions, but mostly to their greater steadiness or constancy of direction over long distances, thus enabling them to bring in air from considerably warmer or colder regions respectively. Instances are not infrequent, especially in winter, when a steady NW. or SW. wind prevails in the upper levels over a major portion of the country. Moreover, as will be explained later, these winds have a smaller deviation from the surface upward than do others, and form therefore what may be called a nearly "solid" current in a vertical as well as in a horizontal sense.

From Table 2 it is possible to compute the average lapse rates, °C. per 100 m., for the different directions. This has been done and the results are presented in Table 3, in 3 groups, viz, surface to 1,000 meters, 1,000 to 3,000 meters, and surface to 3,000 meters.

TABLE 3.—*Average temperature lapse rates (°C. per 100 m.), for different surface wind directions at Drexel, Nebr., and Ellendale, N. Dak.*

[Highest and lowest values indicated by bold face and italic type, respectively.]

SURFACE TO 1,000 METERS, M. S. L.

Surface wind direction.	Drexel, Nebr.					Ellendale, N. Dak.				
	Spring.	Summer.	Autumn.	Winter.	Annual.	Spring.	Summer.	Autumn.	Winter.	Annual.
N	**0.71**	0.68	0.45	0.20	0.50	0.52	0.68	0.25	−0.16	0.32
NNE	0.68	0.61	0.36	0.03	0.43	0.49	0.54	0.16	−0.32	0.22
NE	0.64	0.59	0.28	−0.05	0.38	0.41	0.40	0.22	−0.29	0.20
ENE	0.54	0.58	0.15	−0.17	0.26	0.45	0.36	0.16	−0.25	0.18
E	0.48	0.50	0.10	−0.36	0.08	0.52	0.47	0.04	−0.31	0.18
ESE	0.43	0.43	0.23	−0.41	0.17	0.52	0.59	0.16	−0.23	0.26
SE	0.41	0.40	0.30	−0.40	0.20	0.54	0.65	0.23	−0.07	0.34
SSE	0.41	0.48	0.21	−0.38	0.08	0.47	0.56	0.02	−0.29	0.20
S	0.46	0.53	0.20	−0.45	0.08	0.25	0.41	−0.26	−0.90	−0.13
SSW	0.48	0.50	0.12	−0.64	0.10	*0.00*	0.26	*−0.29*	*−1.12*	*−0.29*
SW	0.41	0.43	*0.05*	*−0.69*	*0.05*	0.07	*0.14*	−0.11	−0.88	−0.23
WSW	*0.33*	*0.33*	*0.05*	−0.51	*0.05*	0.14	0.23	0.02	−0.49	−0.02
W	0.50	0.36	0.17	−0.26	0.20	0.45	0.43	0.20	−0.11	0.25
WNW	0.69	0.51	0.33	−0.02	0.38	0.56	0.58	0.40	0.09	0.41
NW	**0.71**	0.68	0.48	0.08	0.51	**0.58**	0.68	**0.49**	**0.16**	**0.47**
NNW	0.69	**0.74**	**0.53**	**0.28**	**0.56**	0.56	**0.76**	0.41	0.05	0.45

[4] Blair, Wm. R.: Free-air data: Sounding balloon ascensions at Indianapolis, Omaha, and Huron. *Bulletin of the Mount Weather Observatory.* Vol. 4, pt. 4, pp. 192-193. 1912.

TABLE 3.—*Average temperature lapse rates (°C. per 100 m.), for different surface wind directions at Drexel, Nebr., and Ellendale, N. Dak.*—Continued.

1,000 METERS TO 3,000 METERS, M. S. L.

Surface wind direction.	Drexel, Nebr.					Ellendale, N. Dak.				
	Spring.	Summer.	Autumn.	Winter.	Annual.	Spring.	Summer.	Autumn.	Winter.	Annual.
N	0.38	0.52	0.37	0.12	0.35	0.36	0.48	0.30	0.12	0.32
NNE	0.38	0.53	0.40	*0.09*	*0.35*	*0.32*	*0.44*	*0.30*	0.06	*0.28*
NE	*0.38*	*0.52*	0.41	0.12	0.36	0.33	0.45	0.36	0.06	0.30
ENE	0.38	0.52	0.45	0.19	0.38	0.40	0.46	0.42	0.13	0.36
E	0.38	0.56	0.50	0.28	0.42	0.54	0.48	0.44	0.13	0.40
ESE	0.42	0.56	0.49	0.31	0.44	0.57	0.52	0.38	0.06	0.38
SE	0.46	0.59	0.49	0.26	0.45	0.48	0.53	0.34	*0.02*	0.34
SSE	0.50	0.63	0.50	0.22	0.46	0.45	0.55	0.38	0.10	0.37
S	0.53	0.66	0.48	0.24	0.48	0.50	0.62	0.44	0.27	0.46
SSW	0.56	0.70	0.49	0.32	0.52	0.56	**0.69**	0.50	0.40	0.54
SW	0.60	**0.71**	0.54	0.44	0.58	0.56	**0.69**	**0.58**	**0.50**	0.58
WSW	**0.62**	0.70	**0.62**	**0.48**	**0.60**	0.63	0.66	0.57	**0.50**	**0.59**
W	0.60	0.68	0.59	0.44	0.58	**0.68**	0.64	0.54	0.46	0.58
WNW	0.55	0.68	0.48	0.36	0.52	0.60	0.62	0.49	0.38	0.52
NW	0.48	0.65	0.41	0.26	0.45	0.64	0.60	0.44	0.28	0.45
NNW	0.41	0.58	*0.36*	0.17	0.38	0.58	0.54	0.38	0.20	0.38

SURFACE TO 3,000 METERS, M. S. L.

Surface wind direction.	Drexel, Nebr.					Ellendale, N. Dak.				
	Spring.	Summer.	Autumn.	Winter.	Annual.	Spring.	Summer.	Autumn.	Winter.	Annual.
N	0.46	0.56	0.39	0.13	0.38	0.40	0.52	0.29	0.05	0.32
NNE	0.45	0.55	0.40	*0.08*	0.37	0.36	0.46	*0.27*	*−0.02*	*0.27*
NE	0.45	0.54	*0.38*	*0.08*	0.36	*0.35*	*0.44*	0.33	−0.01	0.28
ENE	0.42	*0.53*	*0.38*	0.11	*0.36*	0.41	*0.44*	0.37	0.05	0.32
E	*0.40*	0.54	0.40	0.13	0.37	0.54	0.48	0.35	0.04	0.35
ESE	0.42	0.53	0.43	0.14	0.38	0.56	0.54	0.34	0.00	0.36
SE	0.45	0.55	0.45	0.11	0.39	0.50	0.56	0.31	0.00	0.36
SSE	0.48	0.59	0.44	0.08	0.40	0.45	0.55	0.30	0.01	0.33
S	0.54	0.63	0.42	0.08	0.41	0.45	0.58	0.29	0.02	0.33
SSW	0.54	0.65	0.40	0.10	0.42	0.44	0.60	0.33	0.07	0.36
SW	0.56	0.64	0.43	0.17	0.45	0.43	0.57	0.43	0.20	0.40
WSW	0.55	0.61	0.48	0.25	0.48	0.52	0.57	0.45	0.29	0.46
W	0.57	0.61	**0.49**	**0.28**	**0.49**	**0.63**	0.59	0.46	**0.34**	**0.50**
WNW	**0.58**	0.64	0.45	0.27	0.48	0.59	0.61	**0.47**	0.32	0.50
NW	0.53	**0.66**	0.43	0.24	0.46	0.49	**0.62**	0.45	0.26	0.45
NNW	0.48	0.62	0.40	0.20	0.42	0.44	0.59	0.39	0.17	0.40

The first two sections of this table indicate a very nearly opposite relation of lapse rate to wind direction in the lower and in the higher levels. From the surface to 1,000 meters, M. S. L. (about 600 meters actually, the station altitudes being, Drexel 396 and Ellendale 444), lapse rates are lowest with SSW. to WSW. and highest with NW. and NNW. winds: from 1,000 to 3,000 meters they are *highest* with SW. and WSW., and *lowest* with N. to NE. winds.

Southerly winds are of course cooled at the surface as they move to higher latitudes; this cooling produces a stable condition of the air and therefore does not extend to the upper levels. Northerly winds, on the other hand, are warmed at the surface in their progress toward lower latitudes, and this warming *does* extend to the upper levels, in diminished degree of course, since it tends to a condition of instability and therefore convectional activity sets in.

This characteristic difference in temperature lapse rates accompanying northerly and southerly winds is reflected in the decrease of relative humidity from the surface to the 1,000-meter level. As is well known, surface southwesterly winds in general are least humid, and northeasterly most humid.[5] The values in Table 4 show that this difference extends to the upper levels, at any rate to 4 kilometers. Only the annual values for Drexel are given, as those for Ellendale and for all seasons at both stations are essentially the same as these so far as distribution with wind direction is concerned. The last column of the table contains the average decrease in relative humidity from the surface to the 1,000-meter level. From these figures it is seen that the largest

[5] See figs. 24 and 25 in conjunction with figs. 8 and 10 in *A statistical study of surface and upper-air conditions in cyclones and anticyclones passing over Davenport, Iowa*, by A. D. Udden. MO. WEATHER REV. February, 1923, 51: 58 and 61.

decrease occurs with SW. and WSW. winds and the smallest with N. and NNW. winds. As already stated, air going northward is cooled at the surface. As a result of this cooling the relative humidity rises, but that in the upper levels suffers no change. Hence, the large decrease in the first 500 meters or so. Air going southward, on the other hand, is warmed at the surface, but this warming and the resulting decrease in relative humidity are propagated upward by convectional activity, so that there is a fairly even distribution at all levels.

TABLE 4.—*Average annual relative humidities for different surface wind directions at Drexel, Nebr.; also, average decrease from surface to 1,000 m.*

[Highest and lowest values indicated by bold face and italic type, respectively.]

Surface wind direction.	Altitude above M. S. L. (meters).					Decrease, surface to 1,000 meters.
	396	1,000	2,000	3,000	4,000	
N.	73	**70**	60	58	59	*3*
NNE.	74	69	**62**	62	66	5
NE.	74	68	**62**	65	68	6
ENE.	**75**	67	**62**	65	69	8
E.	**75**	66	**62**	**66**	**70**	9
ESE.	74	65	61	64	65	9
SE.	72	63	58	59	59	9
SSE.	69	61	59	56	57	8
S.	68	57	52	53	53	11
SSW.	65	52	48	49	48	13
SW.	*64*	*48*	*45*	*47*	48	**16**
WSW.	*64*	*48*	47	48	50	**16**
W.	66	53	50	50	48	13
WNW.	66	58	53	49	*44*	8
NW.	69	64	55	51	46	5
NNW.	72	69	57	54	52	*3*

The second section of Table 3 indicates the characteristic lapse rates in the air above the direct influence of surface warming or cooling. By reference to Table 4 it will be seen that the driest winds, SW. and WSW., have the largest lapse rates, and the wettest winds, NNE. to E. those with which precipitation most frequently occurs, have the smallest lapse rates. The differences give striking testimony to the effect of latent heat of condensation upon vertical temperature distribution. This effect is most pronounced, or at any rate of most frequent occurrence, in the lower layers of the atmosphere, from about 500 to 3,000 meters above the surface, where condensation is most active. At higher levels the lapse rate is more nearly constant regardless of wind direction. Evidence of this approach to the same value is to be found in Table 2. Owing to the small number of observations at 4 kilometers with easterly surface winds, only the general features can be considered significant, but these show mean annual lapse rates between 3 and 4 kilometers varying from about 0.55 with northerly winds to about 0.65 with southerly winds at both Drexel and Ellendale. These lapse rates increase to about 0.65 and 0.70, respectively, at still greater heights, thus approaching but never quite reaching the same value. This approach to a constant lapse rate is presumably due to vertical movement of the air, upward in southerly, downward in northerly winds and attendant changes in humidity, condensation in the former, evaporation in the latter. The final result is lower temperature and greater height of the stratosphere above southerly than above northerly surface winds. Figure 1 shows this relation very satisfactorily.

Thus far we have considered the relations between free-air temperatures and wind directions at the surface. The contention may be made that a north or south component at the surface *does not necessarily mean* a north or south component, respectively, in the upper levels. This is correct: Observations show that in some instances a north component wind at the surface turns into a south component wind in the free air and vice versa, but they also show that in the great majority of cases the component that is dominant at the surface persists at all levels. The results of a detailed analysis of the data have been presented in Tables 18a to 19c, inclusive, of "An Aerological Survey of the United States."[6] and need therefore be only briefly referred to here. Excluding the E. and W. surface directions and combining the remaining directions into groups, we find the following percentage frequencies of north and south components at 3 and 4 kilometers:

TABLE 5.—*Average annual percentage frequencies of north and south components at 3 and 4 kilometers.*

Surface wind directions.	North component at—		South component at—	
	3 Kilometers.	4 Kilometers	3 Kilometers.	4 Kilometers.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
WNW.-ENE.	89	89		
NW.-NE.	92	89		
NNW.-NNE.	94	90		
ESE.-WSW.			81	76
SE.-SW.			85	77
SSE.-SSW.			89	82

It is not surprising to find higher values with north than with south component winds. The normal turning with altitude is clockwise, except in the case of NW. to NE. winds which more frequently turn counterclockwise. However, they rarely back beyond a westerly direction. ENE. winds tend to a clockwise turning but this direction rarely occurs and therefore the total number of north component winds that change with altitude to a south component is comparatively small. Southerly surface winds, on the other hand, veer in a majority of cases, the frequency and amount of the turning being greatest with ESE. and least with WSW. winds. ESE. to SSW. winds seldom turn into a westerly direction, but those from SW. and WSW. have a north component at 3 and 4 kilometers in about 50 per cent of the cases. However, the deviation is usually small and the mean direction at 3 and 4 kilometers is almost exactly west, whereas the mean direction of surface WNW. and NW. winds at these levels is some 20° to 30° north of west. It thus appears that, even though the SW. and WSW. surface winds have a north component at the upper levels in about half the cases, their mean direction is nevertheless from a point considerably farther south than is that of the WNW. and NW. surface winds.

If we exclude these and consider only the NNW.-NNE. and SSE.-SSW. surface winds, we find from Table 5 that the percentage frequency of N. and S. components is 94 and 89, respectively, at 3 kilometers, and 90 and 82 at 4 kilometers. From Table 2 we can compute the mean annual temperatures for these direction groups. The figures follow:

TABLE 6.—*Mean annual temperatures (°C.), at various heights corresponding to winds having definite north and south components.*

Surface wind direction.	Altitude above M. S. L. (meters).									
	Drexel, Nebr.					Ellendale, N. Dak.				
	396	1,000	2,000	3,000	4,000	444	1,000	2,000	3,000	4,000
NNW.-NNE.	6.2	3.6	1.0	−3.6	−9.2	2.9	1.0	−1.1	−5.5	−10.7
SSE.-SSW.	12.5	11.5	7.8	1.8	−4.6	7.8	8.2	5.1	−1.0	− 7.3

[6] MO. WEATHER REV. SUPPLEMENT NO. 20, 1922.

The extent to which a north or south component prevails at heights above 4 kilometers is not known. An examination of pilot-balloon observations indicates that winds with a north component at the surface have the same component at 8 to 10 kilometers in a majority of cases, but that those with a south component at the surface have a north component at these levels more frequently than a south component. As a rule, however, this north component is small, so that the mean direction is still several degrees nearer south than is that of the north-component group. In addition it may be remarked that pilot-balloon observations at these great heights can be made only under conditions of exceptional visibility and light wind velocity—those usually found during anticyclonic weather, when, as is well known, the upper pressure distribution is such as to produce west-northwesterly winds. Because of cloudiness and vigorous air movement cyclonic weather is ruled out, so far as investigation by pilot balloons at great heights is concerned. And it is in LOWS, particularly in the central and eastern parts, that we have reason to believe a south component in the upper levels prevails. Occasional observations of upper clouds confirm this view. It seems reasonable, therefore, to conclude with Hildebrandsson [7] as a result of exhaustive studies of cloud data that "there is a slow exchange of air along the meridians, caused by continuous cyclonic and anticyclonic whirls in the Temperate Zones. Indeed each of these whirls carries air on the one side from south to north and on the other from north to south." If this conclusion is well founded, it follows that, as indicated in figure 1, the relation between wind direction and temperature, although less pronounced, is nevertheless operative in the upper levels as well as in the lower.

2. FREE-AIR TEMPERATURES AND FREE-AIR WIND DIRECTIONS.

In order to set at rest any uncertainty as to the conclusiveness of the results discussed in the previous section, based as they are upon the assumption (quite definitely established, however), that a north or south component persists on the average at all levels, we shall here consider the relation in a more direct way, comparing the temperatures at 3 kilometers with the wind directions *actually observed at that level*. All observations made with kites during the summer, June, July, and August, and during the winter, December, January, and February, from 1915 to 1922, inclusive, have been used. The two transition seasons, spring and autumn, have not been included, since the seasonal changes themselves tend to mask those due to any other influences. Inasmuch as certain wind directions, particularly N. through E. to S., are rarely observed at 3 kilometers, some of the directions have been combined into groups, in order that the averages may be based upon a considerable number of observations. Thus, for Drexel and Ellendale, the directions ESE. to SSW. and NNW. to ENE. are grouped; SW., WSW., W., WNW., and NW. are given individually. E. is not included, as there were only 2 or 3 observations with that direction, and it could not of course be combined with other directions, since it has neither a north nor a south component. For the 5 stations other than Drexel and Ellendale the total number of observations is too small to warrant a more detailed grouping than ESE. to WSW., W. and WNW. to ENE. The results in detail for Drexel and Ellendale are presented in Table 7, and the more general results for all stations in Table 8, the number of observations being given in all cases, and the stations being arranged in order of latitude, beginning at the north.

[7] Results of some empiric researches as to the general movements of the atmosphere. Translation by W. W. Reed. MO. WEATHER REV., June, 1919. 47: 389.

TABLE 7.—*Mean temperatures (°C.), for different wind directions at 3 kilometers.*

[No.=number of observations, given in italics; T=temperature in °C.]

SUMMER.

Stations.	Wind directions.													
	ESE.-SSW.		SW.		WSW.		W.		WNW.		NW.		NNW.-ENE.	
	No.	T.	No.	T.	No.	T.	No.	T.	No.	T.	No.	T.	No.	T.
Ellendale, N. Dak...	*37*	8.8	*16*	10.1	*23*	8.1	*24*	6.3	*23*	4.2	*27*	6.4	*19*	3.4
Drexel, Nebr.....	*67*	8.9	*49*	10.6	*27*	9.6	*28*	8.0	*40*	6.5	*38*	5.6	*26*	5.1
	WINTER.													
Ellendale, N. Dak...	*5*	−5.8	*11*	−7.1	*19*	−10.9	*36*	−12.7	*39*	−13.1	*43*	−13.4	*17*	−14.9
Drexel, Nebr.....	*23*	−5.8	*21*	−4.6	*46*	− 5.7	*79*	− 7.2	*82*	−10.7	*68*	− 9.9	*29*	−13.6

The values in this table show that, without exception, temperatures accompanying south component winds are on the average higher than those with north component winds.

TABLE 8.—*Mean temperatures (°C.), for south component winds, ESE.-WSW., west winds, and north component winds WNW.-ENE.*

[No.=number of observations, given in italics; T=temperature in °C.]

Stations.	Wind directions.											
	Summer.						Winter.					
	ESE.-WSW.		W.		WNW.-ENE.		ESE.-WSW.		W.		WNW.-ENE.	
	No.	T.	No.	T.	No.	T.	No.	T.	No.	T.	No.	T.
Ellendale, N. Dak.....	*76*	8.9	*24*	6.3	*93*	5.2	*35*	−8.9	*36*	−12.7	*135*	−13.4
Drexel, Nebr..........	*143*	9.6	*28*	8.0	*104*	6.0	*89*	−5.4	*79*	− 7.2	*179*	−10.9
Royal Center, Ind.....	*32*	8.1	*17*	7.1	*28*	6.1	*29*	−6.8	*20*	− 8.8	*27*	− 8.9
Broken Arrow, Okla...	*61*	9.2	*7*	10.9	*11*	8.7	*23*	−1.0	*7*	− 0.7	*24*	− 6.4
Due West, S. C........	*7*	9.4	*11*	6.3	*9*	7.3	*9*	1.2	*5*	− 0.4	*16*	− 4.4
Leesburg, Ga..........	*9*	8.1	*1*	7.2	*1*	7.6	*8*	3.4	*5*	− 1.3	*14*	− 0.1
Groesbeck, Tex.......	*58*	9.7	*1*	8.6	*14*	8.2	*71*	3.6	*20*	1.8	*39*	− 1.7

As indicated in this table, the mean temperatures with south component winds are higher at all stations and in both seasons than are those with north component winds. Contrasts are greatest in winter, when a strong latitudinal temperature gradient prevails. In general west winds are accompanied by temperatures between those with north and south component winds. The exceptions appear to be due to the small number of observations upon which the means are based.

A point not brought out in the table is the small percentage of cases in which south component winds are accompanied by temperatures lower than the *mean* temperature with north component winds, and vice versa. Table 9 contains this information for Drexel and Ellendale.

TABLE 9.—*Percentage of cases in which temperature with south or north component winds is lower or higher than the mean temperature with north or south component winds, respectively.*

Stations.	South component.		North component.	
	Summer.	Winter.	Summer.	Winter.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Ellendale, N. Dak.	17	23	12	21
Drexel, Nebr.	7	18	26	20

In considering the figures given in Table 8 the question naturally arises as to the height to which this difference in temperatures with north and south component winds extends. No direct answer can be given to this question, but it is significant to note that the difference is greater at 3 kilometers than it is at the surface, as shown in Table 10, in which the surface values are taken from Table 2 and those at 3 kilometers from Table 8.

TABLE 10.—*Comparison of mean temperatures with north and south component winds at the surface and at 3 kilometers.*

DREXEL, NEBR.

Level.	Summer.			Winter.		
	ESE.-WSW.	WNW.-ENE.	Dif.	ESE.-WSW.	WNW.-ENE.	Dif.
Surface	23.9	21.2	2.7	−2.1	−6.7	4.6
3 kilometer	9.6	6.0	3.6	−5.4	−10.9	5.5

ELLENDALE, N. DAK.

Level.	Summer.			Winter.		
	ESE.-WSW.	WNW.-ENE.	Dif.	ESE.-WSW.	WNW.-ENE.	Dif.
Surface	21.5	18.7	2.8	−7.1	−10.1	3.0
3 kilometer	8.9	5.2	3.7	−8.9	−13.4	4.5

It is somewhat surprising to find a greater difference at 3 kilometers than at the surface, but it should not be inferred from this that the difference increases still further at greater heights. As pointed out in the first section of this paper and as indicated in Figure 2, the contrast is greater at 1 to 2 kilometers than it is either below or above.[8] On the other hand it is evident, from Figure 1, that the relation between temperature and wind, though it probably diminishes at heights above 3 kilometers, is nevertheless direct and appreciable to the upper limit of the troposphere.

PROGRESSIVE CHANGES IN FREE-AIR TEMPERATURES ACCOMPANYING STEADY NORTH AND SOUTH COMPONENT WINDS OR CHANGES FROM ONE COMPONENT TO THE OTHER.

Thus far in this paper we have dealt with data from individual observations that are more or less independent of one another, without regard to the time element. It will now be interesting to investigate the changes in temperature that take place during short periods of time with different wind directions. In general kite flights are made once daily. These observations are hardly suited to the present purpose, since they do not show irregular changes that may have occurred during the intervening 24 hours, but fortunately there is available a large number of series of successive flights continuing over periods of 24 to 36 hours, the average length of each flight being in the neighborhood of 3 to 4 hours. In these flights a height of 3 kilometers is reached with sufficient regularity to warrant the use of that level as a basis for the study. At this height surface influences are largely eliminated, and diurnal influences also, since it has been found that the diurnal variation at heights above 2 kilometers is less than 1° C.

Successive flights are made most successfully under conditions of winds moderate in strength and fairly steady in direction. A change to strong or to particularly light winds, or a decided change in wind direction usually means an interruption to the series or its abandonment. Hence we have a large number of observations with winds having a steady north or south component, but comparatively few with a change from north to south component, and vice versa. Even of the latter, however, there are some 70 cases, enough to provide material for a rather conclusive discussion.

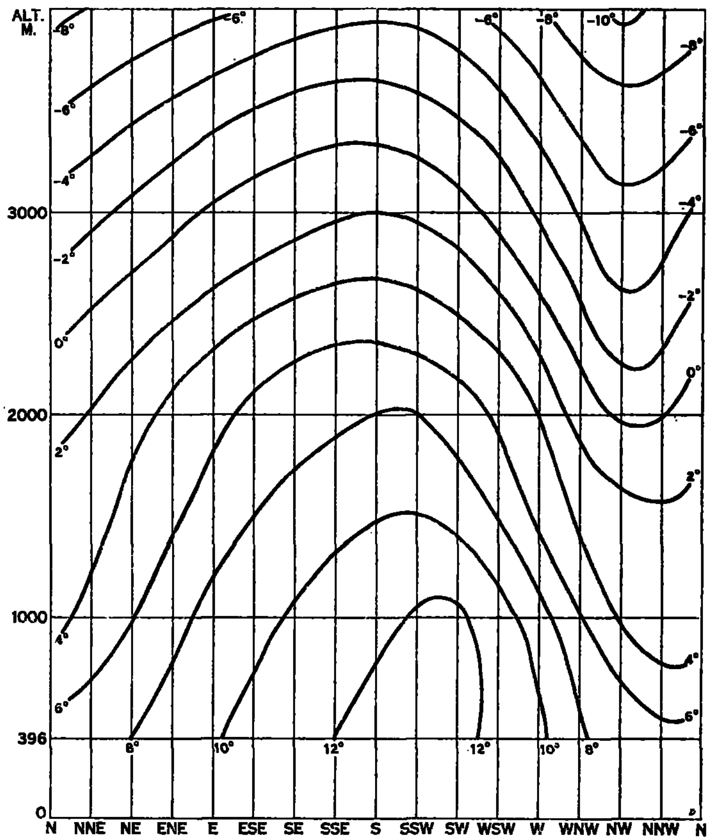

FIG. 2.—Mean annual temperature distribution with surface wind direction at Drexel from the surface to the 4-kilometer level.

An examination of all the data leads to the conclusion that the relations between progressive changes in temperature and wind direction are more pronounced in winter than in summer and at northern than at southern stations. The stations have therefore been considered in two groups—the northern group comprising Drexel, Ellendale, and Royal Center, and the southern, Broken Arrow, Groesbeck, Due West, and Leesburg. Table 11 contains for these two groups and for the seasons as well as the year the percentage frequency of increasing, decreasing, and no change in temperature accompanying winds with north and south components, and winds changing from one component to the other. "No change" in temperature represents a change so small, 1° C. or less, as to be within the limits of observational or instrumental errors.

[8] Cf. Meisinger, C. LeRoy: Preliminary steps in the making of free-air pressure and wind charts. MO. WEATHER REV., May, 1920, 48: 251-263. In conclusion 1 on p. 262 he says: "* * * while wind direction produces a more marked effect upon temperatures aloft than at the surface." In this study conditions in the lowest 2 kilometers only were considered.

TABLE 11.—*Percentage frequency of increasing, decreasing, and no change in temperature at 3 kilometers accompanying winds with north and south components and winds changing from one component to the other.*

[Number of observations in italics.]

Stations.	Wind component. North.				South.				North changing to south.				South changing to north.			
	Temperature change.															
	No.	+	−	0	No.	+	−	0	No.	+	−	0	No.	+	−	0
SPRING.																
Northern	*25*	28	40	32	*50*	67	20	13	*10*	100	0	0	*5*	20	60	20
Southern	*8*	37	63	0	*20*	60	15	25	*3*	100	0	0	*1*	0	100	0
Combined	*33*	30	46	24	*50*	64	18	18	*13*	100	0	0	*6*	16	67	17
SUMMER.																
Northern	*17*	35	41	24	*50*	40	32	28	*4*	100	0	0	*4*	50	25	25
Southern	*2*	0	100	0	*24*	63	8	29	*0*	....	....	....	*2*	0	50	50
Combined	*19*	32	47	21	*74*	47	24	29	*4*	100	0	0	*6*	33	34	33
AUTUMN.																
Northern	*40*	42	38	20	*45*	60	22	18	*5*	80	0	20	*11*	9	82	9
Southern	*12*	42	50	8	*26*	46	23	31	*1*	100	0	0	*1*	100	0	0
Combined	*52*	42	41	17	*71*	55	22	23	*6*	83	0	17	*12*	17	75	8
WINTER.																
Northern	*39*	28	59	13	*17*	76	24	0	*15*	80	13	7	*5*	20	60	20
Southern	*14*	36	21	43	*13*	62	15	23	*4*	50	0	50	*3*	33	67	0
Combined	*53*	30	49	21	*30*	70	20	10	*19*	74	10	16	*8*	25	63	12
ANNUAL.																
Northern	*121*	34	45	21	*142*	56	26	18	*34*	88	6	6	*25*	20	64	16
Southern	*36*	36	45	19	*83*	56	16	28	*8*	75	0	25	*7*	29	57	14
Combined	*157*	35	45	20	*225*	56	22	22	*42*	86	5	9	*32*	22	62	16

Although in the majority of cases the normal relation between wind direction and temperature was found, i. e., falling temperature with north component winds and vice versa, especially with winds changing from one component to the other, yet the table shows that there were many exceptions. We shall now consider in more or less detail some of the individual series of observations, both types of relations being included. All of the 456 cases have been studied, but only a few can be given here. Those selected are not exceptional, but rather typical of the whole number.

DECREASING TEMPERATURES WITH NORTH COMPONENT WINDS.

As indicated in Table 11 there were 157 series of observations with north component winds. Of these 45 per cent showed decreasing temperatures. A few examples follow:

December 4–5, 1916, Table 12.—Weather conditions at Drexel during this series were controlled by a very active LOW which moved from north of Montana to Ontario. Pressure was relatively high, but with no well-defined center, in the Southern and Western States. Cooling was marked at all levels up to 4 kilometers and presumably much higher. The air that was brought in by the WNW. winds evidently originated far to the northward on the western side of the LOW.

TABLE 12.—*Drexel, Nebr., winds and temperatures at 3 kilometers, December 4–5, 1916.*

1916	Dec. 4.		Dec. 5.		
Time	12 m.	4 p. m.	12 midnight.	4 a. m.	10 a. m.
Wind	WNW.	WNW.	WNW.	WNW.	WNW.
Temp. °C.	−0.6	−2.3	−7.3	−10.4	−10.6

Surface wind, WNW. veering to NW. and later backing to W.; surface pressure rose 19 mb.

January 24–25, 1919, Table 13.—As indicated in Figures 3 and 4, there was a decided difference in pressure conditions on the two days during which this series of flights was made. On the 24th Ellendale was under the influence of an active LOW central north of Montana. During the next 24 hours this LOW diminished greatly in energy and moved eastward to Ontario. In the meantime high pressure, with no well defined center, spread over much of the Rocky Mountain and Great Plains regions. Free-air temperatures at Ellendale bore a close relation to this change in pressure distribution. While the LOW was dominant, upper winds brought in air that originated a considerable distance northward, as may be inferred from the isobars in Figure 3. By nightfall of the 24th the influence of this LOW was superceded by that of the western HIGH with its gently curving isobars. Thereafter little change in temperature occurred because the source of the air, even though the wind direction at Ellendale was still WNW., was evidently not to the north but rather to the west along the northern part of the HIGH, as can be seen by a glance at Figure 4. This HIGH was probably of greater vertical extent than normal for this season of the year, owing to the absence of any well-defined horizontal temperature gradient.

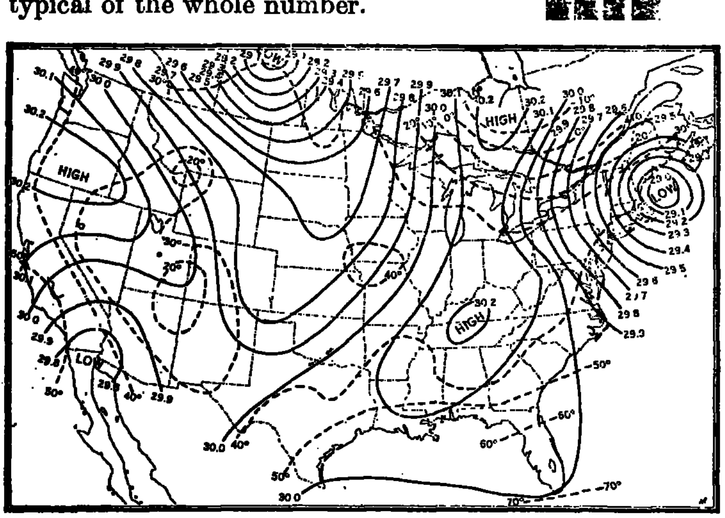

FIG. 3.—Pressure and temperature distribution, 8 a. m., 75th meridian time, Jan. 24, 1919.

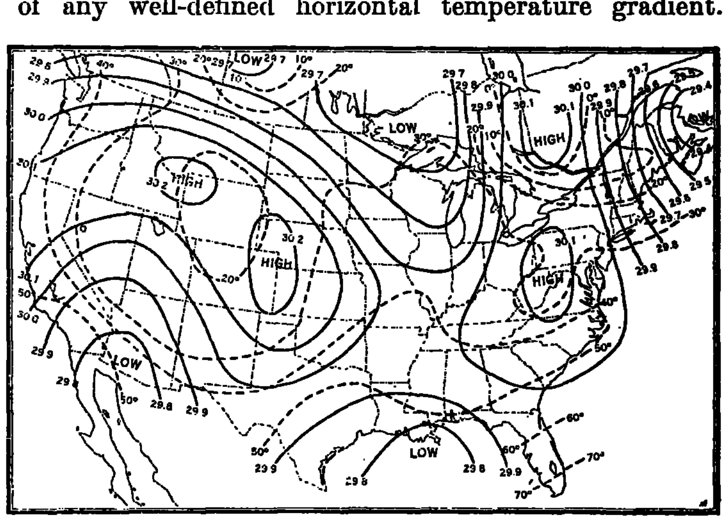

FIG. 4.—Pressure and temperature distribution, 8 a. m., 75th meridian time, Jan. 25 1919.

This supposition is borne out by an observation at Drexel on the 25th, which showed a NNW. wind at 3 kilometers, essentially parallel to the sea-level isobars and a temperature only 2° C. higher than that at Ellendale as against a normal difference of 5° C. Presumably then the free-air isobars in the northern part of the HIGH were closely similar to those at sea level, and the source of the air supply at Ellendale was a considerable distance westward. It may be added as significant that on the following day, 26th, the free-air temperature had risen some 5 or 6° C., the wind direction still being WNW., which indicates that by this time air originating from the Pacific coast in the northwestern part of the HIGH was passing Ellendale. This seems reasonable from the fact that the speed of the free-air winds was about 50 m. p. h., or 1,200 miles per day—approximately the distance from Ellendale to the coast.

TABLE 13.—*Ellendale, N. Dak., winds and temperatures at 3 kilometers, January 24–25, 1919.*

1919	Jan. 24.				Jan. 25.		
Time	12 m.	3 p. m.	7 p. m.	10 p. m.	7 a. m.	11 a. m.	2 p. m.
Wind	WNW	W	WNW	WNW	NW	WNW	WNW.
Temp., °C	−7.3	−11.4	−14.1	−14.0	−13.6	−13.8	−14.1.

Surface wind, NW. backing to SW., then veering to WNW., surface pressure rose 6 mb.

March 5–6, 1920, Table 14.—Pressure conditions were unusually active during these two days. On the morning of the 5th a well-developed LOW was central over eastern North Carolina; this moved to a position just off the New England coast during the next 24 hours. Meanwhile a HIGH of great magnitude advanced from central Alberta to Montana. There was a steep temperature as well as pressure gradient between these, the air in the upper levels at Leesburg coming from a long distance to the north. On the day following this series, 7th, the upper wind was still WNW. and a further cooling had occurred. Conditions at Royal Center, somewhat farther north, were closely similar to those at Leesburg. Free-air winds at 3 kilometers were continuously NW. from the 5th to 7th and during this period there was a fall in temperature from −15 to −23° C.

TABLE 14.—*Leesburg, Ga., winds and temperatures at 3 kilometers, March 5–6, 1920.*

1920	Mar. 5.			Mar. 6.		
Time	3 p. m.	7 p. m.	11 p. m.	3 a. m.	8 a. m.	1 p. m.
Wind	WNW	WNW	WNW	WNW	WNW	WNW.
Temp., °C.	−2.4	−3.0	−3.6	−7.0	−9.7	−10.9.

Surface wind, NW; surface pressure rose 8 mb.

February 25–26, 1921, Table 15.—During this series a well-developed LOW moved from just north of the Dakotas southeastward to lower Lake Michigan. Of more importance, so far as free-air winds are concerned, was an area of intense cold between the upper Lakes and Hudson Bay. This produced in the upper levels an *eastward* shift of the LOW center from its sea level position, the reverse of normal; a steep pressure gradient northeastward from Drexel; and resulting strong NW. winds.

TABLE 15.—*Drexel, Nebr., winds and temperatures at 3 kilometers, February 25–26, 1921.*

1921	Feb. 25.			Feb. 26.	
Time	9 a. m.	1 p. m.	4 p. m.	2 a. m.	12 m.
Wind	WNW	WNW	WNW	NW	NNW.
Temp., °C	−2.9	−1.0	−3.5	−8.9	−8.2.

Surface wind, SSW. veering to NNW.; surface pressure fell 12, then rose 14 mb.

Toward the end of the series a moderate HIGH developed over the central Rocky Mountain region and a LOW considerably farther north. It is evident that the free-air winds during the first day brought in air from the north, but on the second day from a more westerly quarter. This change is reflected in the small increase in temperatures from 2 a. m. to noon, Feb. 26, given in the table.

INCREASING TEMPERATURES WITH NORTH COMPONENT WINDS.

Fifty-four series of observations, or 35 per cent of all cases, showed increasing temperatures. This is a much larger proportion of exceptions than is found in any of the other three groups given in Table 11. It is thought well worth while, therefore, to give particular attention to some of the more conspicuous examples, most of which occurred at northern stations.

November 29–30, 1918, Table 16.—In two of the cases previously discussed there occurred a change in the source of the air supply from a northerly to a westerly point, with resulting temperature change, although the wind direction itself at the place of observation remained constant. In the series now under consideration this change in air source had proceeded yet further, as can be seen by a glance at the isobars in Figures 5 and 6. It is evident that the air flowing past Ellendale originated on the western side of the HIGH, some little distance off the coast. In this connection it may be

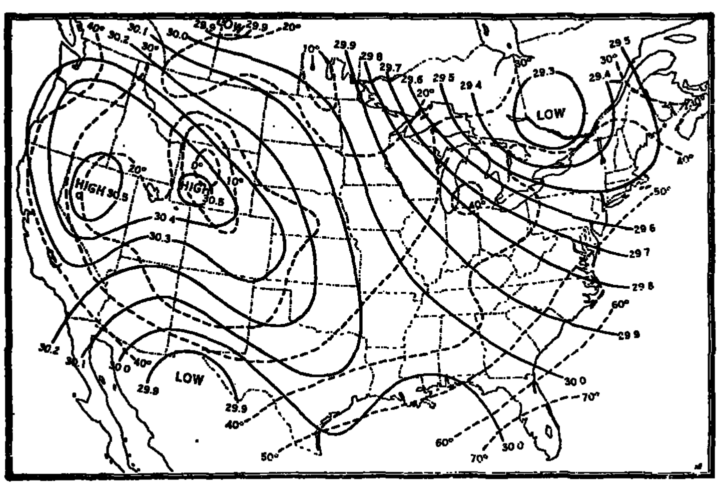

FIG. 5.—Pressure and temperature distribution, 8 a. m., 75th meridian time, Nov. 29, 1918.

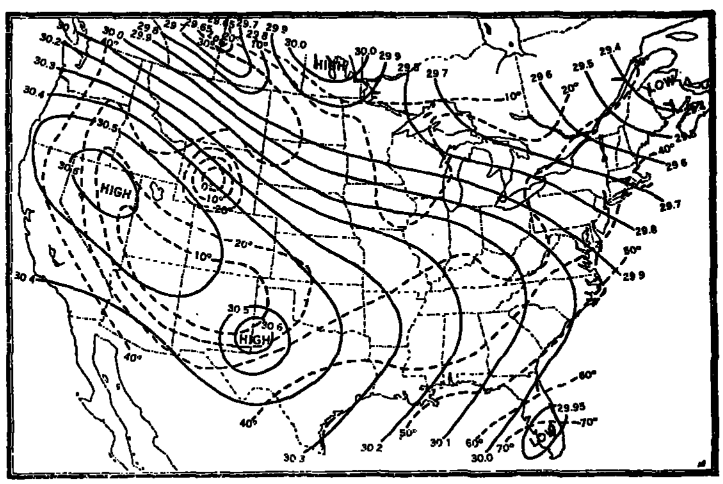

FIG. 6.—Pressure and temperature distribution, 8 a. m., 75th meridian time, Nov. 30, 1918.

remarked that temperatures at all levels were lower on the 29th than on the 28th, when the HIGH extended considerably farther north and brought to Ellendale successively colder masses of air.

TABLE 16.—*Ellendale, N. Dak., winds and temperatures at 3 kilometers, November 29–30, 1918.*

1918	Nov. 29.				Nov. 30.				
Time	10 a. m.	2 p. m.	6 p. m.	9 p. m.	1 a. m.	4 a. m.	7 a. m.	10 a. m.	1 p. m.
Wind	WNW.	NW.	NW.	NW.	NW.	NW.	NW.	NNW.	NNW.
Temp., °C.	−21.9	−18.8	−18.2	−17.4	−15.5	−13.8	−11.0	−10.0	−7.8

Surface wind, NW. backing to WSW., then veering to N.; surface pressure fell 7 mb.

Too much importance should not be attached to the higher temperatures on the west side of the northwestern LOW shown in Figures 5 and 6, than on its east side. As is well known, this is characteristic of North Pacific coast LOWS but in all probability is confined to low levels. Its principal effect, in conjunction with that of a reverse temperature distribution at higher levels, would be a greater tendency to symmetry with height, i. e., the absence of pronounced northwestward shift of the LOW center. In all probability the increasing temperatures at Ellendale were caused by warm air being brought from a southerly point round the northern side of the HIGH rather than by air at approximately the same latitude which was warm owing to the ocean's influence, for this latter is almost certainly in large part a surface phenomenon.

As indicated in the figures, Drexel was in the same general air stream as was Ellendale, upper winds on the 28th to 30th being northwesterly and the temperatures falling from the 28th to 29th and rising from the latter to the 30th.

December 15–17, 1919, Tables 17 and 18.—These two series are considered together, because they overlap each other as to time and because the conditions in the Far West during these three days were markedly uniform. An unusually well-developed and active HIGH was central over southern Idaho throughout this period. Not only was it stationery in position, but also practically constant as to intensity, varying but little from 30.8 inches at its center. There was a moderate LOW, also stationary for the most part, just north of Montana. Temperature contrasts were marked, there being low values in the main part of the HIGH, where clear weather prevailed and radiation was active, and high temperatures on all sides, those to the northeast being presumably the result of chinook action.

TABLE 17.—*Broken Arrow, Okla., winds and temperatures at 3 kilometers, December 15–16, 1919.*

1919	Dec. 15.			Dec. 16.		
Time	12 m.	5 p. m.	10 p. m.	7 a. m.	11 a. m.	3 p. m.
Wind	WNW.	WNW.	W.	WNW.	W.	WNW.
Temp., °C.	−8.0	−8.0	−5.7	−4.6	−2.1	−1.4

Surface wind, SSW.; surface pressure fell 7 mb.

TABLE 18.—*Drexel, Nebr., winds and temperatures at 3 kilometers, December 16–17, 1919.*

1919	Dec. 16.			Dec. 17.		
Time	10 a. m.	2 p. m.	10 p. m.	5 a. m.	10 a. m.	2 p. m.
Wind	WNW.	WNW.	WNW.	W.	NW.	NW.
Temp., °C.	−7.5	−8.4	−4.2	−5.0	−3.6	−1.4

Surface wind, NW. veering to NNE. and later to SSE.; surface pressure rose 2, then fell 6 mb.

When this HIGH first came southward, it brought to the western part of the country a large mass of cold air, as indicated by observations at Ellendale, Drexel, and Broken Arrow where a decided decrease in temperatures occurred at all heights reached—3 to 4 kilometers. As soon, however, as the HIGH became stationary and an appropriate circulation was established, this cold air to the east was displaced by warmer air originating on the western side of the HIGH and flowing round its northern side. This condition was widespread, both horizontally and vertically, being apparent at the 3 stations above named and being almost as pronounced at 4 kilometers as near the surface, extending presumably therefore to the upper limit of the troposphere. At 3 kilometers pressure remained unchanged, the rise in temperature of the air column being offset by a fall in the surface pressure, as indicated in the tables.

January 9–10, 1920, Table 19.—As indicated in the table, the course of temperature change was not progressively in one direction, but consisted first of a rise and then of a fall. During this entire period pressure was again exceedingly high in the Plateau region, and it is significant to note that pressure was highest over southern Idaho on the 9th, but over Washington on the 10th, apparently due to mergence with another HIGH advancing from British Columbia. With this change there was apparently an alteration in the circulation, the air flowing past Drexel no longer coming from the Pacific Ocean round the northern part of the HIGH, but from the Canadian Northwest. This influence was of considerable duration, as revealed by an observation on the 11th, which showed a temperature of −17° C. at 3 kilometers, or a further drop of more than 5° C. It is worthy of remark also that on the day preceding this series, 8th, the HIGH, already well developed, was central over Washington and that the temperature at Drexel and 3 kilometers fell 4° C. during the next 24 hours. Thus, during the entire period, 8th to 11th, inclusive, there was intimate relation between the free-air temperature and the position of the HIGH, i. e., the source of the air supply.

TABLE 19.—*Drexel, Nebr., winds and temperatures at 3 kilometers, January 9–10, 1920.*

1920	Jan. 9.				Jan. 10.			
Time	10 a. m.	2 p. m.	6 p. m.	9 p. m.	1 a. m.	5 a. m.	9 a. m.	2 p. m.
Wind	W.	WNW.	WNW.	WNW.	WNW.	WNW.	WNW.	WNW.
Temp., °C.	−16.1	−13.8	−10.2	−8.4	−9.1	−9.1	−10.2	−11.4

Surface wind, SSW. veering to NNW.; surface pressure fell 2, then rose 7 mb.

December 18–19, 1922, Table 20.—This series is of special interest because it illustrates not only the dependence of free-air temperatures upon the source of the air supply, but also the close relation between horizontal temperature distribution in the lower levels and free-air pressures and winds. As indicated in Figures 7 and 8, temperatures just north of the Great Lakes and along the Gulf coast differed by slightly more than 100° F. This steep gradient was characteristic of much of the month, as shown in MONTHLY WEATHER REVIEW Chart III, "departure of mean temperature from normal," and as discussed on pages 658 to 661 of that journal for December, 1922. In conformity with it, free-air winds were westerly and fairly strong over pretty much the entire country.

TABLE 20.—*Drexel, Nebr., winds and temperatures at 3 kilometers, December 18–19, 1922.*

1922	Dec. 18.				Dec. 19.	
Time	10 a. m.	2 p. m.	6 p. m.	11 p. m.	6 a. m.	10 a. m.
Wind	W.	WNW.	WNW.	WNW.	WNW.	W.
Temp., °C.	−12.0	−10.4	−11.4	−9.9	−6.1	−5.5.

Surface wind, SSW.; surface pressure fell 14 mb.

The increase in temperature with a north component wind at 3 kilometers appears in this case, as in others already cited, to be due to the air's having followed a curved path round the northern part of a practically stationary HIGH. In the present instance a vigorous LOW from the Pacific coast doubtless contributed; it is significant to note that the temperature rose decidedly although the surface pressure fell, a good example of the usual condition in this country, i. e., cyclones warmer than anticyclones. A similar warming occurred at Ellendale, but in this case the upper wind changed from WNW to W and WSW under the influence of the advancing LOW.

INCREASING TEMPERATURES WITH SOUTH COMPONENT WINDS.

Table 11 shows that 225 series of observations were made with the upper wind continuously from a southerly direction. In 56 per cent of these a rise in temperature occurred at 3 kilometers. Good examples of this relation between wind direction and temperature are found in 2 series of flights on March 30–31, 1920, one at Drexel and the other at Royal Center.

March 30–31, 1920, Tables 21 and 22.—During this period a moderate but well-developed HIGH was central over the Southeastern States and a very active LOW in the Northwest, the latter moving from slightly north of Montana to North Dakota, a comparatively short distance. The temperature gradient from north to south was about normal for this season of the year. Hence, winds from a southerly direction naturally brought to the different stations air that was progressively warmer. That this was a general condition over most of the country east of the Rockies is shown by observations at Ellendale, Broken Arrow, Groesbeck, and Leesburg, where free-air conditions prevailed similar to those at Drexel and Royal Center.

TABLE 21.—*Drexel, Nebr., winds and temperatures at 3 kilometers, March 30–31, 1920.*

1920	Mar. 30.				Mar. 31.	
Time	10 a. m.	2 p. m.	5 p. m.	9 p. m.	1 a. m.	12 m.
Wind	W.	WSW.	SW.	SW.	SW.	SW.
Temp., °C.	−4.9	−2.6	−3.5	−4.2	−1.0	0.4.

Surface wind, SW.; surface pressure fell 16 mb.

TABLE 22.—*Royal Center, Ind., wind and temperatures at 3 kilometers, March 30–31, 1920.*

1920	Mar. 30.			Mar. 31.	
Time	10 a. m.	5 p. m.	8 p. m.	12 midnight.	11 a. m.
Wind	W.	W.	WSW.	SW.	SW.
Temp., °C.	−9.0	−6.4	−5.0	−4.4	−2.4.

Surface wind, WSW. backing to S.; surface pressure stationary.

June 10–11, 1920, and January 6–7, 1922, Tables 23 and 24.—These two cases are very good examples of winter and summer types, respectively. In the one case we have steep temperature and pressure gradients and therefore vigorous cyclonic and anticyclonic development and movement; in the other, weak and irregular gradients and sluggish pressure conditions, "flat maps." These characteristic differences are strikingly reflected in the two sets of data above tabulated. In each case a wind with south component prevailed and a rise in temperature occurred, but in winter this rise amounted to more than 11° C. whereas in summer it was less than 3°. The difference may be said to be "one of degree, not one of kind."

TABLE 23.—*Broken Arrow, Okla., winds and temperatures at 3 kilometers, June 10–11, 1920.*

1920	June 10.			June 11.			
Time	10 a. m.	4 p. m.	8 p. m.	6 a. m.	9 a. m.	2 p. m.	5 p. m.
Wind	S.	SSW.	SSW.	SSW.	S.	SSW.	S.
Temp., °C.	6.6	8.6	6.5	8.3	8.4	9.6	9.4.

Surface wind, S.; surface pressure fell 2, then rose 6 and finally fell 3 mb. Gradients, both pressure and temperature, were of the summer type—weak and irregular. A moderate HIGH covered the Southeastern and Eastern States and an ill-defined LOW was central over the Dakotas. Temperature was only slightly higher in the South than in the North.

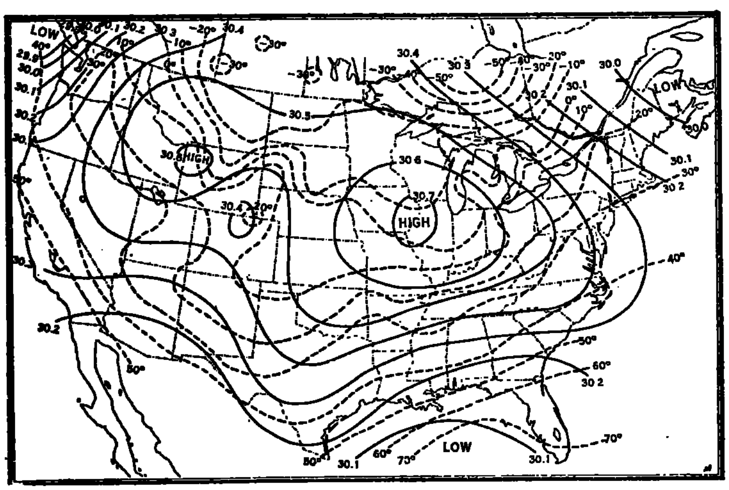

FIG. 7.—Pressure and temperature distribution, 8 a. m., 75th meridian time, Dec. 18, 1922.

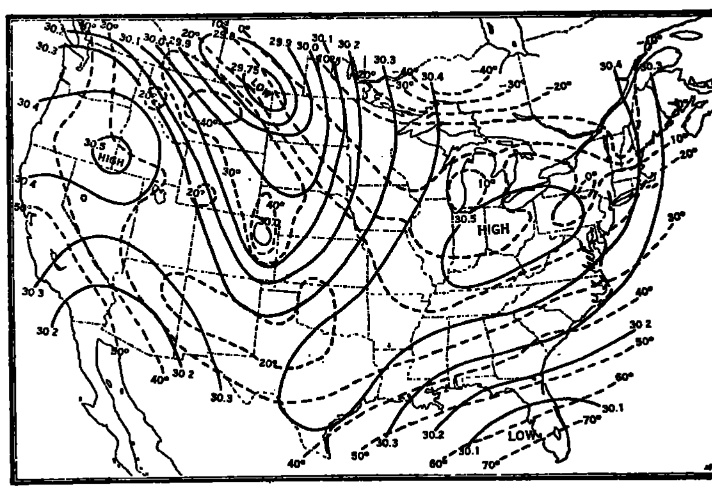

FIG. 8.—Pressure and temperature distribution, 8 a. m., 75th meridian time, Dec. 19, 1922.

Table 24.—*Drexel, Nebr., winds and temperatures at 3 kilometers, January 6–7, 1922.*

1922	Jan. 6.		Jan. 7.			
Time	1 p. m.	9 p. m.	1 a. m.	5 a. m.	9 a. m.	1 p. m.
Wind	WSW.	SW.	SW.	WSW.	W.	WSW.
Temp., °C.	−16.2	−15.0	−14.8	−12.4	−7.5	−4.9.

Surface wind, S.: surface pressure fell 4 mb. A pronounced and well-developed HIGH covered the eastern part of the country on these two days, its center moving from Illinois and Iowa to the Lower Lake region. Weather conditions at Drexel were controlled by this HIGH throughout the series.

The temperature change at Drexel apparently increased with altitude, there being a rise of 9.8° C. from 1 p. m. to 9 a. m. at 4 kilometers. Increases in free-air temperature with southwesterly winds occurred on these two days also at Broken Arrow and Ellendale.

DECREASING TEMPERATURES WITH SOUTH COMPONENT WINDS.

There were 49 cases of this type, or 22 per cent of the total. For the most part the change in temperature was small, but in a few instances it was considerable. Data for a few of these are given in the following examples:

November 8–9, 1917, Table 25.—This period is remarkable in that practically no precipitation occurred in any part of the United States; in fact, from 8 a. m. of the 8th to the same hour of the 9th, 75th meridian time, the only rainfall reported was 0.01 inch at Tatoosh Island, Wash., and the same amount at Eastport, Me. Pressure was high everywhere; centers of activity were in the Plateau region and over the eastern half of the country, with only relatively low pressure between them. The western HIGH increased considerably in intensity from the 8th to 9th, and this development was accompanied by a material cooling on its eastern side, particularly in Utah and Colorado. Meanwhile a very weak LOW (its lowest pressure was above 30 inches) formed over western South Dakota and Nebraska. From this development of HIGH and LOW there resulted a more active circulation between the two, the SSW. winds at Drexel now bringing in colder air from the southeastern quadrant of the HIGH. The change occurred near midnight and was rather abrupt. Accompanying it was a very pronounced increase in relative humidity from 1 kilometer upward and the rapid formation of St Cu, following several days of practically cloudless weather. The temperature decrease was confined to a shallow stratum, there being none at 1 and 2 kilometers and less at 3½ than at 3 kilometers. This case is a very good example of polar air being brought southward on the eastern side of a HIGH and then diverted northward round a LOW in too short a time to enable it to assume the temperatures more or less approaching the normal of the latitudes which it passes.

Table 25.—*Drexel, Nebr., winds and temperatures at 3 kilometers, November 8–9, 1917.*

1917	November 8.				November 9.			
Time	12 m.	4 p. m.	7 p. m.	11 p. m.	2 a. m.	6 a. m.	11 a. m.	3 p. m.
Wind	S.	SSE.	SSW.	SSW.	SSW.	SSW.	SSW.	S.
Temp., °C	3.0	0.8	1.0	1.0	−3.4	−3.6	−1.6	−3.4.

Surface wind, SE.; surface pressure fell 7 mb.

June 9–10, 1920, Table 26.—High pressure with no well-defined center, overlay the Eastern States and there was a moderate LOW in the extreme Southwest. Temperature gradients were from E.–W. instead of N.–S., in other words, temperatures were lower west and southwest of the station than they were at the station itself; hence the SSW. winds at Drexel drew in air from a cooler region. It seems likely that this cooler air was first brought southward by a moderate HIGH that was central in Washington on the 9th. Thus it often happens that a HIGH or LOW which appears to have no direct relation to the weather at a given place may in reality, in an indirect way, be responsible for the changes that occur, which is only another way of saying that meteorological phenomena are never wholly local in character but are subject to influences whose only limits are those of the entire atmosphere itself.

Table 26.—*Drexel, Nebr., winds and temperatures at 3 kilometers, June 9–10, 1920.*

1920	June 9.			June 10.				
Time	9 a. m.	4 p. m.	8 p. m.	12 midnight.	4 a. m.	7 a. m.	11 a. m.	3 p. m.
Wind	WSW.	SSW.	SW.	SW.	SW.	SSW.	SSW.	SSW.
Temp., °C.	10.5	9.4	9.2	8.2	8.0	8.2	7.2	6.8.

Surface wind, WSW. backing to SSW.; surface pressure stationary.

The northwestern HIGH diminished in intensity from the 9th to 10th and as a result the southward flow of cool air ceased. Hence, it is found that free-air temperatures at Drexel increased during the 24 hours following this series, i. e., from the 10th to 11th, with SSW. winds; also at Broken Arrow as shown in Table 23 and accompanying discussion.

May 25–26, 1922, Table 27.—This series is of special interest not only as showing polar air from a southerly quarter, but also because of the prevalence of easterly winds to great heights. Pressure and temperature conditions over the country at 8 a. m., 75th meridian time, of each day are shown in Figures 9 and 10. The air in the

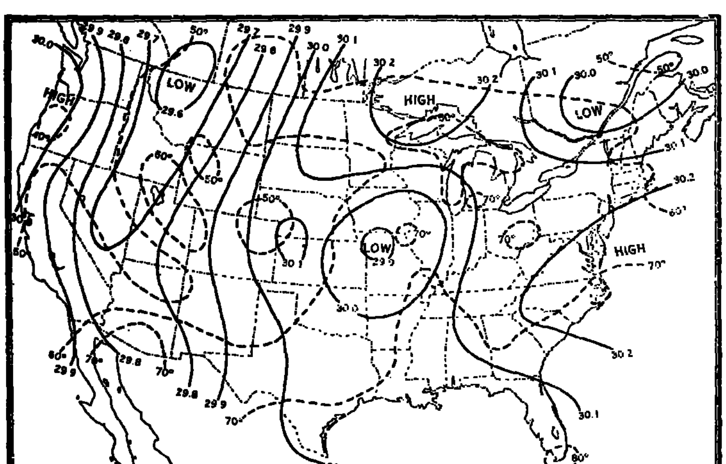

Fig. 9.—Pressure and temperature distribution, 8 a. m., 75th meridian time, May 25, 1922.

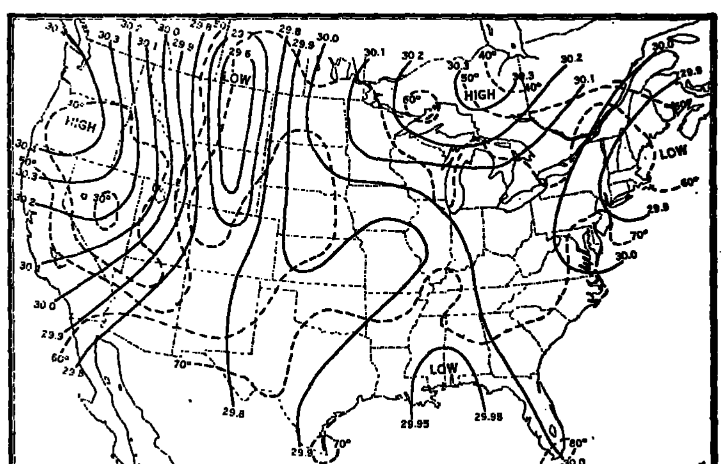

Fig. 10.—Pressure and temperature distribution, 8 a. m., 75th meridian time, May 26, 1922.

SE. and ESE. winds at Ellendale on the 26th evidently originated from the eastern side of the HIGH central north of the upper Lakes. This view is supported by observations at Lansing and Madison, where the free-air winds were NE. and E., respectively. On the following day, 27th, the same wind structure prevailed, viz, NE. at Lansing, E. at Madison, and SE. at Ellendale. By this time, however, the HIGH had developed further and spread eastward and temperatures had appreciably risen. As a natural consequence we find that, between the 26th and 27th, a small increase in free-air temperature at Ellendale occurred. It is worthy of note also that even from the 25th to 26th the decrease at Ellendale, as in some cases previously discussed, did not extend much above 3 kilometers. At 4 the change was only about 1° C.

TABLE 27.—*Ellendale, N. Dak., winds and temperatures at 3 kilometers, May 25-26, 1922.*

1922	May 25.			May 26.		
Time	1 p.m.	6 p.m.	11 p.m.	5 a.m.	10 a.m.	1 p.m.
Wind	E.	E.	E.	SE.	SE.	ESE.
Temp., °C.	5.8	5.6	5.1	4.2	3.8	1.0.

Surface wind, ESE.; surface pressure practically stationary.

Further inspection of Figures 9 and 10 shows that unusually high temperatures for this season of the year prevailed in the northern part of the country and that the gradient southward was very small. It is not surprising, therefore, to find free-air easterly winds, particularly since the temperature distribution was associated with a higher pressure in the North than in the South. That these winds were of great vertical extent is indicated by a balloon run at Ellendale on the morning of the 25th, when ENE. backing to NNE. were observed between 3,500 and 7,000 m. There was a further backing to NNW. at 10 kilometers, but at all levels the speed was low, averaging 5 to 6 m. p. s. Very much the same condition prevailed on the afternoon of this day, but by the 26th the speed had increased to about 15 m. p. s. and the direction had veered to SE at heights between 1 and 5 kilometers. A kite flight on the 27th showed that the wind was still SE. at 4 kilometers, although the speed had diminished to about 10 m. p. s.

With the development and eastward extension of the upper Lakes HIGH, already referred to, and the continuation of a weak temperature gradient from the north to south, the upper easterly current gradually spread over much of the northern and eastern portions of the country, being most pronounced on the 27th and 28th, then extending southward on the 29th and 30th; in all cases reaching altitudes between 5 and 8 kilometers.

In connection with this general westward drift it is interesting to note that cyclonic development and movement were practically at a standstill. For instance, as shown in Figures 9 and 10, the LOW central over northern Missouri on the 25th had nearly disappeared by the 26th, and completely so by the 27th. It may be added that this same LOW in its earlier stages moved from the 22d to 25th only about 200 miles, viz, from eastern Oklahoma to northern Missouri. During this period also free-air easterly winds were general. A northwestern LOW had a somewhat similar history. As indicated in Figure 10, this LOW on the 26th was a troughlike depression extending from just north to just south of eastern Montana. On the 27th practically no trace of it remained, an excellent example of a "dying cyclone," because of little temperature variation on all sides. As already stated, the upper easterly current extended southward after the 28th and in this connection it is significant to note that a LOW of small intensity but accompanied by considerable precipitation remained in practically a stationary position just south of Mississippi and Alabama from the 28th to 31st.

INCREASING TEMPERATURES WITH WIND CHANGING FROM NORTH TO SOUTH COMPONENT.

Of the 42 series of observations made with this type of wind change (see Table 11) 86 per cent showed a progressive increase in free-air temperatures, the increase usually being very pronounced. Data for two series on March 9-10, 1921, at Drexel and Royal Center are given in Tables 28 and 29.

TABLE 28.—*Drexel, Nebr., winds and temperatures at 3 kilometers, March 9-10, 1921.*

1921	Mar. 9.				Mar. 10.	
Time	9 a.m.	1 p.m.	5 p.m.	9 p.m.	1 a.m.	2 p.m.
Wind	WNW	WNW	WNW	WSW	WSW	W.
Temp., °C.	−16.2	−13.8	−11.2	−11.8	−9.0	−2.6.

Surface wind WSW.; surface pressure fell 15 mb; weather generally clear, except for 5/10 to 7/10 Ci and Ci St between 4 and 8 p. m. on the 9th.

TABLE 29.—*Royal Center, Ind., winds and temperatures at 3 kilometers, March 9-10, 1921.*

1921	Mar 9.			Mar. 10.			
Time	11 a.m.	3 p.m.	7 p.m.	2 a.m.	7 a.m.	10 a.m.	2 p.m.
Wind	SW	WSW	WNW	WNW	WSW	W	W.
Temp., °C.	−9.7	−10.7	−12.8	−11.0	−8.7	−6.7	−6.7.

Surface wind NNW. backing to SSW.; surface pressure rose 6 then fell 3 mb; during the first day there was considerable cloudiness of intermediate types; after 6 p. m. weather was clear.

These two series, when considered together and in connection with the weather maps, bring out some interesting points. For one thing they show the essential conformity of free-air winds, i. e., isobars, to horizontal temperature gradients, to a large extent regardless of changes in surface pressure distribution introduced by passing HIGHS and LOWS. This is clearly seen by comparing the wind directions at 3 kilometers, as above tabulated, with the pressure and therefore wind changes occurring at the surface as shown in Figures 11 and 12. On the 9th at Royal Center surface winds were NNW., as would be expected, but at 3 kilometers they were SW. or WSW., substantially parallel with the isotherms. As the HIGH moved eastward the trend of the isotherms changed to WNW.-ESE. and later to W.-E., winds at 3 kilometers meanwhile veering to WNW. and then backing to W. Similar changes occurred at Drexel. That the latitudinal temperature gradient was steep at 3 kilometers as well as at the surface, is shown by observations with kites at Broken Arrow and Groesbeck, as follows:

TABLE 30.—*Temperatures at 3 kilometers on March 9-10, 1921, at Drexel, Broken Arrow, and Groesbeck.*

1921	Mar. 9.		Mar. 10.
Time	10 a.m.	3 p.m.	10 a.m.
Drexel	−15.5	−12.5	−5.0.
Broken Arrow	−9.5		−0.6.
Groesbeck		0.2	

The normal difference at 3 kilometers in March between Drexel and Broken Arrow is 3.9° C., and between Drexel and Groesbeck, 7.3° C.

Observations with pilot balloons also show that in all parts of the country east of the Rockies and north of central Florida winds at 3 kilometers were between SW. and NW. and in 75 per cent of the cases they were between WSW. and WNW.

It is significant that the HIGH shown in Figures 11 and 12 moved almost directly east from the 9th to 10th, in close agreement with the air movement generally prevailing at 3 kilometers. It is interesting further to note that on the morning of the 8th winds above 2 kilometers at Ellendale and Drexel were NNW. to WNW. At this time the HIGH was central just north of Montana. Its movement south-southeastward was in good agreement with the trend of the isotherms and the resulting free-air winds.[9]

The foregoing discussion constitutes to some extent a digression from the main purpose of this paper, but in studying any body of meteorological data one usually comes across many points of interest which seem to merit some attention but which would very likely not receive such attention unless first introduced as "side issues," so to speak. Later these may themselves become the bases of separate studies. We shall now return to the subject in hand.

The dependence of free-air temperatures upon the source of the air supply is convincingly shown in the tabulations above given for Drexel and Royal Center. The HIGH, central north of Montana on the morning of the 8th, brought with it a large mass of polar air. At Drexel on this morning wind and temperature at 3 kilometers were WNW. and −11°C., respectively. As the HIGH moved southward the wind remained WNW. or perhaps veered to NW. and the temperature continued to fall—to what value is not known, but at 9 a.m. on the 9th it was −16.2°C. Thereafter with the eastward movement of the HIGH and the accompanying change in the trend of surface isotherms the wind at 3 kilometers gradually backed to WSW. and the temperature rose very decidedly.

The records at Royal Center are of special interest in that they show the temperature changes accompanying a change in wind from south to north and later from north to south component. In the first flight on the 9th at 11 a. m. the wind at 3 kilometers was still SW. in substantial parallelism with the surface isotherms, although the influence of the HIGH was already apparent in the lower levels, the winds there being NNW. By 7 p.m., the winds at 3 kilometers had veered to WNW. and the temperature had fallen from −9.7° to −12.8° C. Thereafter, with further advance of the HIGH past the station and accompanying change in the isothermic distribution the winds backed to WSW. and W. and the temperature rose to −6.7° C. On the 11th this HIGH was central some distance off the middle Atlantic coast, the wind at 3 kilometers was WSW. and the temperature had risen still further to −3.2° C.

During the latter part of this month a series of 8 flights at Ellendale, made in connection with rapid and pronounced changes in pressure, gave an excellent illustration of the normal relation between free-air winds and temperatures, as discussed in the following paragraphs.

March 28–29, 1921, Table 31.—This series was made near the end of a period of exceptional barometric activity, the main features of which, so far as meteorological conditions at Ellendale are concerned, was a well-developed HIGH preceded and followed by equally well-developed LOWS. The first LOW assumed definite character on the morning of the 26th when it was central over southeastern Colorado, the lowest pressure being 29.2 inches. During the next 24 hours it moved, with undiminished vigor, to Lake Superior and was accompanied by general precipitation and high winds. Thereafter it decreased in energy and passed eastward to the St. Lawrence Valley.

TABLE 31.—*Ellendale, N. Dak., winds and temperatures at 3 kilometers, March 28–29, 1921.*

1921	Mar. 28.					Mar. 29.		
Time	8 a. m.	1 p. m.	4 p. m.	8 p. m.	11 p. m.	3 a. m.	8 a. m.	12 m.
Wind	NW.	NW.	NW.	WNW	WNW.	W.	WSW.	WSW.
Temp. °C.	−16.6	−13.4	−10.8	−10.0	−7.1	−3.3	−4.1	−5.2

Surface wind S. veering to SSW.; surface pressure fell 34 mb. (1 inch); weather generally cloudy—mostly A Cu, A St, and Ci St.

Meanwhile a HIGH which appeared in the Canadian Northwest on the 26th advanced southward and was central over Iowa and Nebraska on the morning of the 28th. Thereafter it diminished somewhat in intensity and moved eastward to the Atlantic. A severe cold wave accompanied this HIGH, progressively overspreading sections farther and farther east, and wrought serious damage to all early fruit and much of the later varieties

[9] For a discussion of the relation between free-air winds and the movements of HIGHS and its aid in forecasting, see "Relation between rate of movement of anticyclones and the direction and velocity of winds aloft," by C. L. Mitchell. MO. WEATHER REV., May, 1922. 50: 241–242.

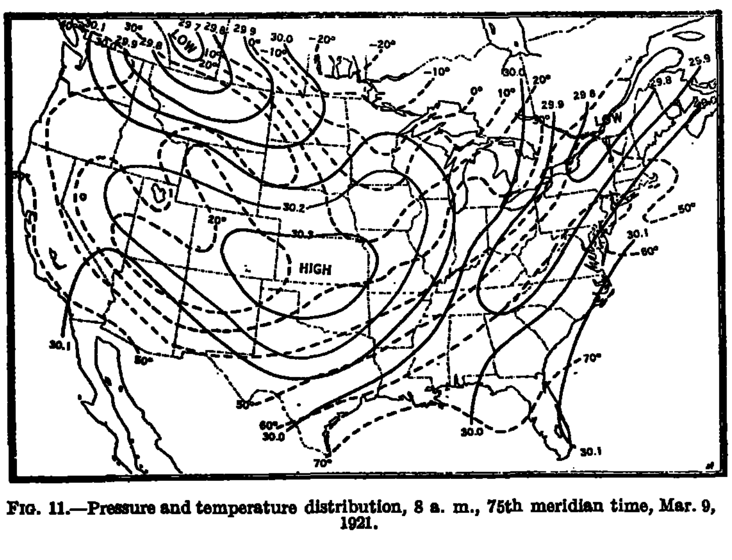

FIG. 11.—Pressure and temperature distribution, 8 a. m., 75th meridian time, Mar. 9, 1921.

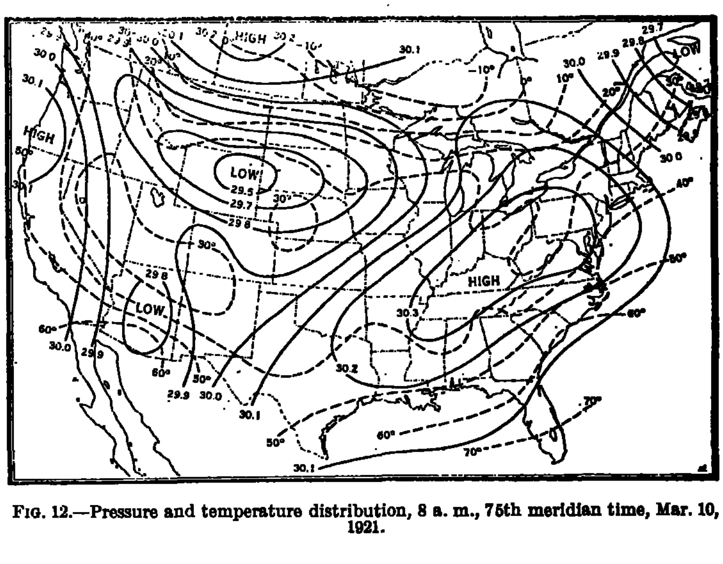

FIG. 12.—Pressure and temperature distribution, 8 a. m., 75th meridian time, Mar. 10, 1921.

over most of the central part of the country. This destruction was especially severe because of abnormally high temperatures which had prevailed during most of the month. The HIGH was followed by a well developed LOW which on the morning of the 29th was central north of the Dakotas with a pressure of 29.2 inches or lower.

Throughout this period a close relationship was found between free-air winds and temperatures. The crest of the cold wave reached Ellendale on the 27th, with the HIGH to the northwest and the LOW central over Lake Superior. Upper winds at Ellendale were generally northwesterly, in close agreement with the trend of the isotherms and with the HIGH's path during the next 24 hours. Temperature at 3 kilometers was −22.4° C. By the next morning, 28th, the HIGH had advanced some distance south of the station and a well-developed LOW was coming in from the northwest, accompanied by a marked rise in temperature. Surface isobars and isotherms between these two systems intersected almost at right angles, with the result that winds in the lower levels at Ellendale were southerly, whereas they were still northwesterly in the upper levels. However, the latter were now bringing in air from a distinctly warmer region than on the day previous under the influence of the LOW. Hence, as shown in Table 31, the temperature at 3 kilometers had increased from −22.4° to −16.6° C. With the eastward movement of both HIGH and LOW from the 28th to 29th the upper winds gradually backed to WSW. and the temperature at 3 kilometers rose with this change to about −4° C. It is interesting to add that on the following day, 30th, with a wind change back to NW., the temperature had fallen to −18° C.

DECREASING TEMPERATURES WITH WIND CHANGING FROM NORTH TO SOUTH COMPONENT.

There were only two cases, 5 per cent of the total, showing a decrease in temperature with this type of wind change, and in each case the amount of the decrease was only 2° to 3° C.

January 24–25, 1921, Table 32.—During this series a fairly well-developed LOW was central in Kansas and practically stationary, and a pronounced HIGH moved east-southeastward from north of Minnesota to north of the upper Lakes, producing colder weather in the Lake region and adjacent districts. It is evident that the ESE. and E. winds at 3 kilometers during the latter part of the series at Ellendale were in reality of polar origin, this air having been brought in bodily by the southward movement of the HIGH. The existence of these upper easterly winds is in itself a matter of interest in view of the rather large north to south temperature gradient. However, the pressure gradient in the lower levels between the HIGH and the LOW was sufficiently steep to offset this influence up to 3 kilometers where the pressure at Drexel and Ellendale was almost identical and the winds therefore of low speed. Cloud observations show that the winds shifted into a westerly quarter at no great height above 3 kilometers.

TABLE 32.—*Ellendale, N. Dak., winds and temperatures at 3 kilometers, January 24–25, 1921.*

1921.	Jan. 24.				Jan. 25.
Time	11 a. m.	3 p. m.	7 p. m.	11 p. m.	4 a. m.
Wind	E.	ENE.	ESE.	ESE.	E.
Temp., °C.	−6.0	−5.6	−6.7	−8.0	−8.4.

Surface wind ENE. backing to NNE.; surface pressure stationary.

In connection with these easterly winds it is significant that the LOW, as already stated, moved very little, only across the state of Kansas—from the 24th to 25th. South of it the upper winds, as observed at Groesbeck, were westerly but very light on the 24th; by the 25th they had increased in strength sufficiently to cause a more rapid movement of the LOW, which on the 26th was central over western Florida. By this time the area of upper easterly winds had advanced east-southeastward with the HIGH but was of limited extent, covering only the region from Indiana to Virginia. Its presence, however, rendered impossible a northward component in the course of the LOW which, as already stated, moved southeastward under the influence of the stronger westerly current still farther south. By the 27th the HIGH had moderated greatly in intensity, easterly winds no longer prevailed at great heights and the LOW was moving slowly east-northeastward some distance off the Atlantic coast.

DECREASING TEMPERATURES WITH WIND CHANGING FROM SOUTH TO NORTH COMPONENT.

Table 11 shows 32 series of observations with this type of wind change. In 62 per cent of these free-air temperatures decreased quite markedly. A good illustration of such decrease is afforded by a series of 7 successive kite flights at Ellendale, N. Dak., on September 24–25, 1918. This series has special interest in that the free-air winds

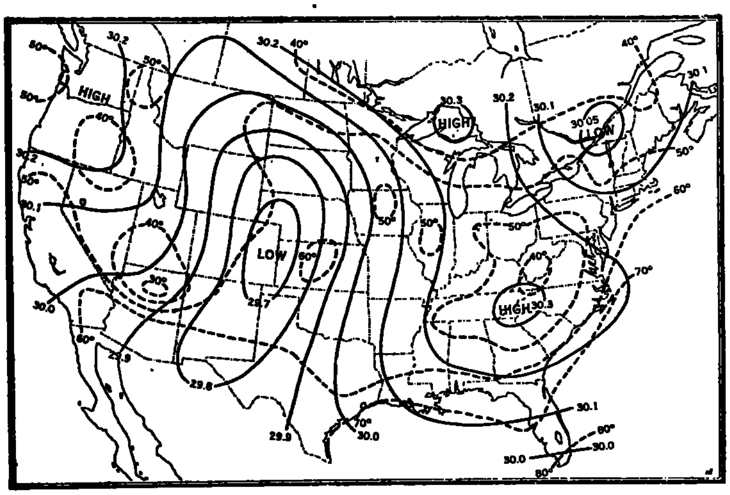

FIG. 13.—Pressure and temperature distribution, 8 a. m., 75th meridian time, Sept. 24, 1918.

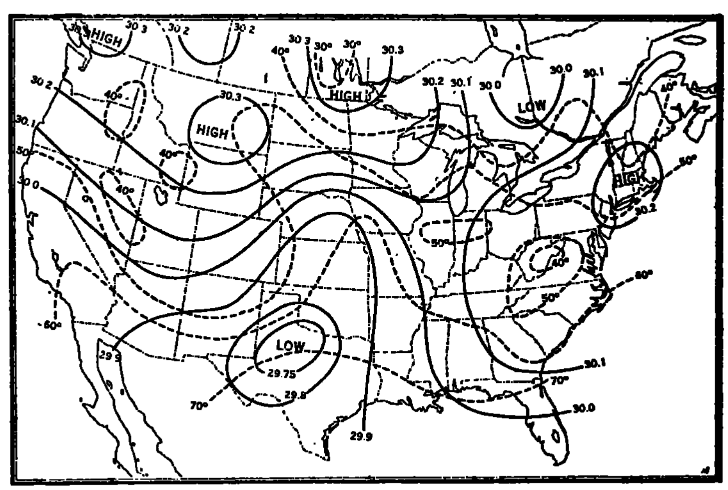

FIG. 14.—Pressure and temperature distribution, 8 a. m., 75th meridian time, Sept. 25, 1918.

up to at least 4 kilometers had an east instead of a west component and were associated with a LOW whose course for this season of the year was decidedly abnormal. The wind and temperature conditions at 3 kilometers are given in Table 33.

TABLE 33.—*Ellendale, N. Dak., winds and temperatures at 3 kilometers, September 24–25, 1918.*

1918	Sept. 24.				Sept. 25.		
Time	9:30 a. m.	1:30 p. m.	6 p. m.	10 p. m.	2 a. m.	6:30 a. m.	11:30 a. m.
Wind, m. p. s.	SSE. 10.	SSE. 8.	E. 12.	ESE. 10.	E. 14.	ENE. 12	NE. 14.
Temp. °C.	6.0	7.0	4.0	1.0	2.4	3.3	2.6.

Winds at the surface were easterly and fairly strong, 10 to 15 m. p. s., in the early part of the series, backing to NNE. and diminishing to 6 to 8 m. p. s. at about midnight. Surface pressure was nearly stationary at 962 mb. until 6 p. m. of the 24th, after which it rose gradually to 971; meanwhile the pressure at 3 kilometers rose from 710 to 714 mb. The change in pressure distribution at Ellendale was very definitely from cyclonic to anticyclonic, as indicated in Figures 13 and 14. The southeasterly winds at 3 kilometers on the 24th and the northeasterly winds on the 25th were distinctly of equatorial and polar origin, respectively. The wind shift occurred first at and near the surface and later progressively at higher and higher levels until on the 25th there was a solid northeasterly current reaching at least to 4 kilometers with little variation in speed, the average being about 12 m. p. s. There were no high clouds on this day, and no free-air observation was made on the 26th, but on the 27th there were about 8/10 Ci St. moving from northeast, notwithstanding that winds up to 5 kilometers were westerly with a speed of 15 to 18 m. p. s. By this time the HIGH north of Ellendale on the 25th had moved southward and covered a wide area, with its center over Nebraska, as shown in Figure 15. It was attended by relatively cool weather whereas farther north the temperatures were from 10° to 15° F. higher, a difference sufficiently large to reverse the pressure gradient at the cirrus level and probably for some distance below it.

The easterly current not only reached great altitudes but also gradually extended over a considerable portion of the interior of the country. Free-air winds at Drexel were southerly on the 24th, backing to southeasterly on the 25th and still farther to northeasterly up to 4,300 meters on the 26th. In all cases these winds were moderately strong, about 12 to 15 m. p. s. except at 3,500 to 4,300 meters on the 26th where their speed fell to 8 m. p. s. This day was cloudless, but on the 27th there were a few Ci from east-southeast. Cloud movement in general, including the cirrus and other high level forms was from east or northeast over the southern and southeastern States on the 27th and 28th.

This deep and widespread easterly drift appears to have been closely associated with a LOW which, first appearing in Idaho on the 21st, gradually moved in a general south-southeastward direction to the Gulf, thence eastward to Florida. The path of this LOW is shown in Figure 16, and its form and position in more detail on the 24th, 25th, and 27th in Figures 13, 14, and 15. Examination of records during the 10-year period, 1913 to 1922, inclusive, brings out the fact that no other LOW has followed a course at all resembling this one during the month of September and only 2 were at all similar to it during the months June to October. The portion of this LOW's journey which is particularly abnormal is that from the 24th to the 26th. During this period temperatures at Drexel and Ellendale between 1 and 3 kilometers were practically the same; hence, free-air isobars conformed closely with those at sea level. On the 24th pressure at 1 and 3 kilometers was identical at the 2 places; on the 25th it was higher by 8 or 9 mb. at Ellendale than at Drexel, a decided reversal of the normal condition. The sea level map of the 24th, Figure 13, shows a fairly steep and approximately uniform pressure gradient on the north, east, and west sides of the LOW, with a somewhat weaker one on the south side.

A 2-kilometer map, Figure 17, prepared in accordance with Meisinger's system of reduction,[10] indicates nearly the same condition with the exception that the major axis extended NNW.-SSE. instead of NNE.-SSW. This free-air distribution of pressures and winds would imply a stationary or at most a slow-moving LOW, and would make impossible a movement to the north, east, or west. To the south, however, the pressure gradient, surface and aloft, was somewhat weaker and in addition there was, as already stated, a lack of symmetry here, the upper isobars crossing those at sea level. The southeastward extension of the LOW is yet more marked at higher levels, as shown in Figure 18, which gives the pressure distribution at 3 kilometers.[11] At 4 kilometers,

[10] The preparation and significance of free-air pressure maps for the central and eastern United States. MO. WEATHER REV. SUPPLEMENT No. 21. W. B. No. 784. 1922.

[11] For the method of computing pressures at 3 and 4 kilometers see "The law of pressure ratios and its application to the charting of isobars in the lower levels of the troposphere." by C. Le Roy Meisinger, MO. WEATHER REV. September, 1923. 51:437–443. It is interesting to note that the *computed* pressure at Omaha was 20.94 inches, and the *observed* pressure at Drexel, 20 miles west, was also 20.94 inches.

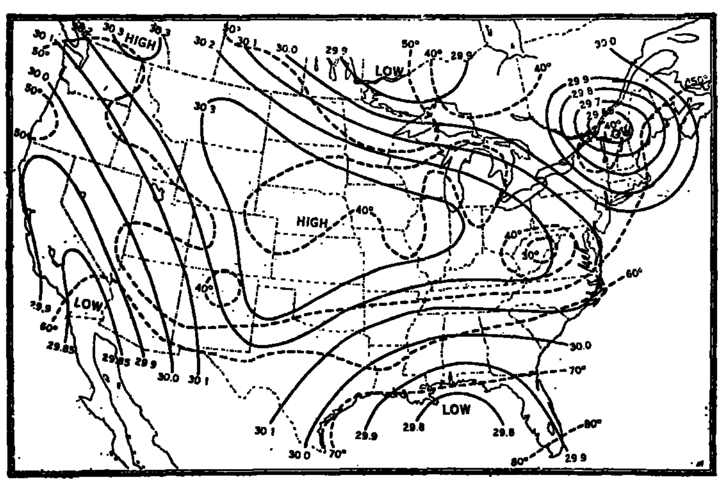

FIG. 15.—Pressure and temperature distribution, 8 a. m., 75th meridian time, Sept. 27, 1918.

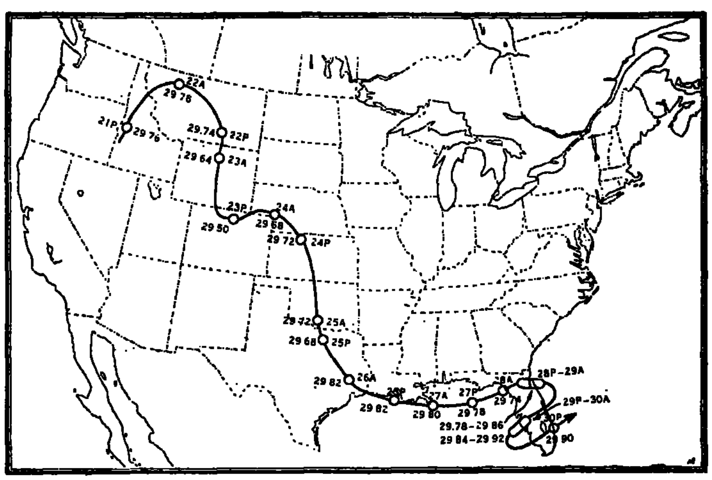

FIG. 16.—Track of center of LOW from Sept. 21 to 30, 1918, inclusive.

the map for which is not reproduced here, the pressure was about the same over Arkansas and over Wyoming, with somewhat higher pressure between the two centers. This free-air pressure distribution is decidedly abnormal, there being ordinarily a northwestward shift of the LOW center with altitude. The presence of the free-air LOW to the southeast of its sea level position seems in this case to have been due to comparatively low temperatures at and near the surface in the southern part of the country. As indicated in Figure 13, surface temperatures varied little from Texas to Wisconsin. Apparently there was a reversal in the upper levels, a kite flight at Broken Arrow showing a temperature 2° C. lower at 1,000 meters than that observed at Drexel. Unfortunately the observation at Broken Arrow extended only to this height.

The free-air pressure distribution above outlined appears to have been influential in determining the course of the sea-level LOW. Its movement eastward was blocked by the upper easterly winds already referred to. Southward, however, as indicated in Figures 13, 17, and 18, there was a marked difference in the isobars at the surface and in the free air, the two systems being approximately at right angles to each other. This condition, coupled with the probably greater strength of the northwesterly winds on the western side of the LOW than of the southeasterly winds on its eastern side, seems to provide the correct explanation of the observed southward movement. Such movement would have been evident to the forecaster on the morning of the 24th, possibly on the evening of the 23d, had he possessed all of this information as to free-air pressures and winds at those times. In this connection it is interesting to recall that in Japan, where pressure maps for the 3-kilometer level have been used for several years, one of the "rules" resulting from this use is:[12] "Most cyclones showed decided tendencies to move toward the region where unmistakable cross-intersections of upper and lower isobars could be perceived."

A feature of added interest in connection with this LOW is the entire absence of precipitation on its eastern and southern sides until it reached the Gulf on the 26th. North and west of its center, however, rain was general. As the free-air winds changed from southerly to northerly, introducing lower temperatures, relative humidities at both Drexel and Ellendale increased markedly, particularly at 2 to 3 kilometers. A decrease to very low values took place subsequently with the continuance of these northerly winds. While the LOW was traveling eastward along the Gulf coast precipitation was general and in many cases excessive.

Numerous other cases could be cited in which a decrease in temperature at 3 kilometers occurred with a change from south to north component in the wind. As a rule the observations were made with a LOW to the north of the station passing eastward or else with the station successively under the influence of an eastern and a western HIGH. Station pressure either rose continuously or first fell slightly and then rose; in nearly all cases it was higher at the end than at the beginning of the observations. The amount of the temperature decrease was dependent primarily upon the steepness of the latitudinal gradient; to some extent also upon the angle through which the wind changed. The time of the wind change usually coincided very closely with that of largest temperature change.

November 11–12, 1918, Table 34.—During this series the station was first under the influence of a HIGH over the St. Lawrence Valley; later, of a HIGH central over Northwest Wyoming. An interesting feature is the recovery of temperature with a change from NNW. to WNW. wind between the last two flights.

TABLE 34.—*Drexel, Nebr., winds and temperatures at 3 kilometers, November 11–12, 1918.*

1918.	Nov. 11.				Nov. 12.		
Time	9 a. m.	1 p. m.	5 p. m.	9 p. m.	1 a. m.	4 a. m.	8 a. m.
Wind	WSW.	WSW.	W.	WNW.	NNW.	NNW.	WNW.
Temp. °C.	2.1	2.0	2.1	−0.5	−1.7	−4.0	−1.5.

Surface wind SSW. veering to NNW.; surface pressure fell 3, then rose 11 mb.

INCREASING TEMPERATURES WITH WIND CHANGING FROM SOUTH TO NORTH COMPONENT.

This type of wind change was accompanied by increasing temperatures in 7 cases, or 22 per cent of the whole number. The increase was small, however, amounting in no case to more than 3° or 4° C. A good example is found in a series of 4 flights at Due West, S. C., on October 11–12, 1922.

[12] Sekiguchi, Rikichi. High level isobars as used in everyday weather service. MO. WEATHER REV., May, 1922. 50: 242–243.

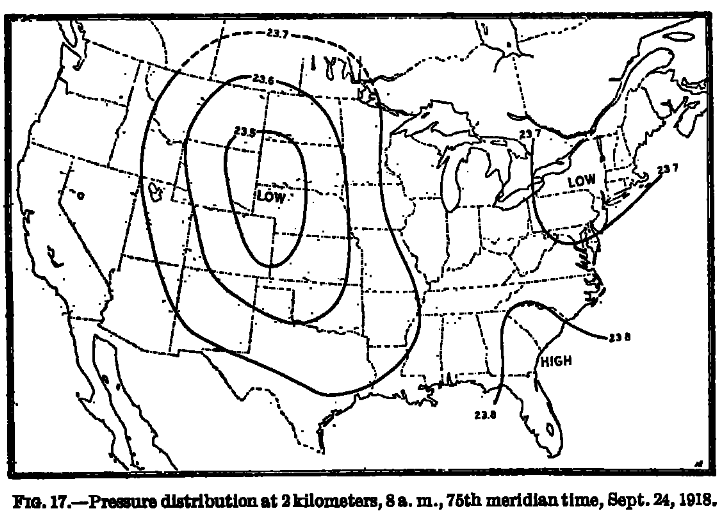

FIG. 17.—Pressure distribution at 2 kilometers, 8 a. m., 75th meridian time, Sept. 24, 1918.

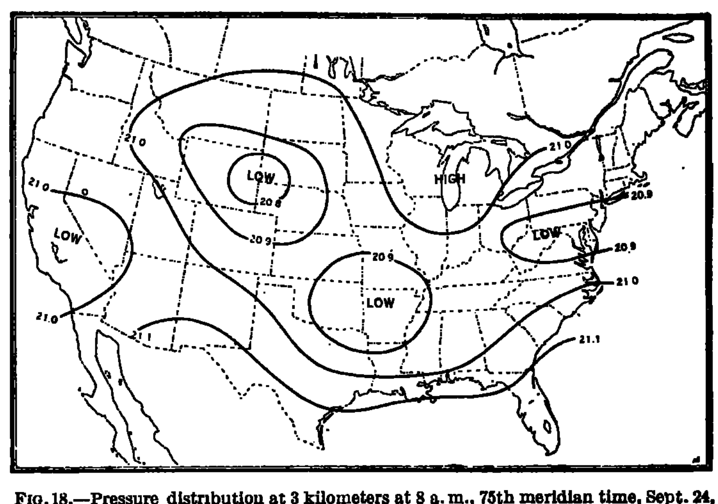

FIG. 18.—Pressure distribution at 3 kilometers at 8 a. m., 75th meridian time, Sept. 24, 1918.

TABLE 35.—*Due West, S. C., winds and temperatures at 3 kilometers, October 11–12, 1922.*

1922	Oct. 11.			Oct. 12.
Time	10 a. m.	2 p. m.	7 p. m.	1 a. m.
Wind	WSW.	WSW.	WNW.	WNW.
Temp., °C.	0.8	3.5	4.6	4.1

Surface wind WSW.; surface pressure fell 1, then rose 3 mb.

During this series a well-developed LOW, central over the Lake region, moved rapidly northeastward to the St. Lawrence Valley, and was followed by a vigorous HIGH whose influence, however, was not felt at Due West until after these flights were completed. It is to be noted that the larger part of the increase occurred between the first and second flights in both of which the wind at 3 kilometers was from WSW. There was a further increase of 1.1° C. as the wind veered to WNW., but the last observation showed a slight decrease with NW. wind. These changes are easily accounted for: Temperatures were essentially uniform in all parts of the LOW, from the upper Lakes southward nearly to the Gulf; still farther south there was a moderate gradient. The WSW. winds at Due West drew from this warmer region; hence, the temperature rose. The WNW. winds, however, came from a region in which the temperatures were practically the same as at Due West; therefore, changes at the latter were unimportant.

SUMMARY AND CONCLUSIONS.

The purpose of this paper, as stated at the beginning, is to determine, so far as possible, the relations between free-air temperatures and wind directions in this country. Before presenting the conclusions, it may be stated that wind direction is of importance mainly in so far as it represents the original source of the air supply. Granting this, it follows that contrasts in temperature with different wind directions are large or small in proportion to the steepness of the latitudinal temperature gradient. As is well known, this gradient is very pronounced in this country but comparatively weak in Europe owing to the marked difference in the climates, one being continental and the other marine, and also because of the effects of the Gulf Stream.[13] As would be expected, therefore, we find greater contrasts in the temperatures accompanying northerly and southerly winds in this country than in Europe. Nevertheless, even in that continent the relationship is direct, on the average, as shown by Mr. C. K. M. Douglas in his "Temperature variation in the lowest 4 kilometers."[14] On page 27 he states:

> Even at the surface there is only a small correlation coefficient between temperature and the south component of the wind but no student of synoptic charts would deny that the origin of the air supply has an important effect on the temperature. In the upper air the effect is not less but rather greater.

There are cases in which the wind direction does not represent at all the original source of the air supply. For instance when a HIGH moves from Alaska into the interior of the United States it brings with it bodily a large mass of cold air. As this HIGH passes a place which is successively in its SW., W., and NW. octants, south component winds prevail, at first SE., then S, and finally SW., yet temperature falls rather than rises because of the approach of the cold air accompanyimg the moving HIGH. In other words, the trajectory of a particle of air passing the place in question is southward instead of northward. The effect of this motion of translation of the HIGH depends upon the rapidity of that motion, as compared with the speed of the winds themselves.

Another and much more frequent case in which the wind direction does not represent the source of the air supply is that of a nearly, or quite, stationary HIGH or LOW around which a fairly definite and characteristic circulation has been established. The most common exception is a HIGH, nearly circular, with its center over Utah or Wyoming.[15] The free-air winds in the northeast quadrant of such a HIGH are WNW. to NNW. and the accompanying temperature not infrequently rises. In every case studied it was plain that the air in this northwesterly wind had originated from the western part of the HIGH at a lower latitude than that of the station itself. Douglas, in the paper above quoted, cites several similar cases in Europe. When a HIGH extends well up into Canada, no such warming occurs, but instead the temperature falls decidedly, the air coming from a long distance to the north.

A type of exception that occurs only in summer is that associated with a complete reversal of latitudinal temperature gradient, with weather sometimes hotter even in southern Canada than in the Southern States. Such exceptions are rare, however.

It is not to be thought that in any region wind direction is the *only* factor to be considered. Other influences, such as radiation intensity, changes in barometric pressure, differences in the quantity and distribution of water vapor, and vertical movement of the air are in operation at all times, each contributing to the final result.[16] But in all considerations of the subject wind direction or the source of the air supply must be included. In regions of little temperature contrast its influence is largely masked by the others; in regions and at times of large horizontal temperature gradient it exercises a larger control than do all of those combined.

With the foregoing remarks in mind, we can state briefly the general conclusions as follows, so far as conditions in the United States are concerned.

1. A north or south component in the winds at and near the surface persists in a majority of cases at all levels in the troposphere and presumably well up into the stratosphere, although the wind direction itself usually changes, e. g., NNW. backing to NW. or WNW.; SE. veering to SW. or WSW.
2. Temperatures accompanying south component winds are on the average considerably higher than those accompanying north component winds at all levels in the troposphere.
3. The difference is more pronounced at 1 and 2 kilometers than at greater heights or at the surface; at 3 and 4 kilometers it is essentially the same as at the surface; above 4 kilometers it gradually diminishes, becoming zero at the upper limit of the troposphere; in the stratosphere the reverse relation is found, viz. lower temperatures with south than with north component winds.
4. The relations given in (2) and (3) are more pronounced in winter than in summer and at northern than at southern stations, i. e., when and where the latitudinal temperature gradient is strongest.
5. Exceptions to the relations given in (2) and (3) are due either to a temporary reversal in the normal latitudi-

[13] Apparently disregarding these differences, some writers treat the results of studies of their own data as having universal application.

[14] *Quarterly Journal of the Royal Meteorological Society.* Vol. XLVII. No. 197, January 1921, pp. 23–43.

[15] An excellent example of this type of exception, in addition to those given in this paper, is that of Jan. 4–5, 1921, at Ellendale, N. Dak., described by L. T. Samuels under "Free-Air Summary." This REVIEW, pp. 46–48.

[16] Humphreys, W. J.: *Physics of the Air*, pp. 53–57. Philadelphia, Pa. 1920.

nal distribution of temperature (occasional summer condition) or to the importation of large masses of cold or warm air in rapidly moving HIGHS or LOWS or to the fact that in some instances the wind direction does not represent the original source of the air, the latter having followed a curved path round a nearly stationary HIGH or LOW.

6. Changes from north to south component winds are in nearly all cases accompanied by rising temperatures, and vice versa.

7. Owing to effects of temperature on air density, the free-air position of a LOW is usually to the northwest of its sea-level position, and that of a HIGH to the southwest. Winds therefore are southwesterly above the sea-level positions of LOWS and northwesterly above the sea-level positions of HIGHS. Under these conditions the air above LOWS is on the average warmer than that above HIGHS, the effects of importation being much greater than those of vertical movement.

8. When easterly winds prevail from the surface up to 3 or 4 kilometers, HIGHS and LOWS are either stationary or their movements are slow and erratic. Such HIGHS and LOWS are nearly circular and probably symmetrical to great heights, air circulation in them is fairly definite and steady, and the effects of vertical movement of the air are greater than those of importation, the centers of HIGHS being warmer than the centers of LOWS.

9. Since in this country symmetrical HIGHS and LOWS, referred to in (8), are less frequent than those with a westward shift of the centers, referred to in (7), it follows that the air above the sea-level positions of HIGHS is on the average colder than that above the sea-level positions of LOWS. If, however, we take the lowest and highest pressures at different heights as the basis of comparison, we find that the lowest pressures are accompanied by the lowest temperatures, the pressure itself at any level being largely a function of the mean temperature of the air column beneath.

A PRELIMINARY STUDY OF PRECIPITATION IN RELATION TO WINDS AND TEMPERATURE.

551.55 : 551.577

By V. E. JAKL, Meteorologist.

(Weather Bureau, Washington, D. C., Dec. 11, 1923.)

As a preliminary step to a more detailed study of upper-air conditions attending precipitation, a statistical study has been made of surface wind directions attending precipitation at the Drexel Aerological Station, Nebraska. The object is to reconcile the frequency, duration, and intensity of precipitation by seasons with position relative to adjoining centers of high and low pressure, or more strictly, with direction of surface isobars. Such a study should form a basis, from which, considered in connection with statistical data already compiled for the upper air, inferences may be drawn relative to the conditions of the atmosphere when precipitation is occurring.

The tabulation in Table 1, column 3, giving the frequency of precipitation in percentage for all parts of a LOW is shown in Figure 1. This figure is intended to be the simplest possible method of showing the sense of direction of the winds relative to the surface isobars; in other words, the directions in Table 1 have been oriented about the center of a composite or imaginary center of low pressure. To allow for the convergence of the arrows toward the center, the table of average deviation of free-air winds from surface winds [1] has been considered, but not strictly adhered to, an average deviation of 20° of surface winds from surface isobars being assumed for all directions and all seasons. Without going into too great detail, and giving separate recognition to the different conditions, this assumption is undoubtedly justified as a general average. Moreover, the averages for all aerological observations can not be rigidly applied to the rather special conditions prevailing during precipitation.

[1] Gregg, W. R.: An Aerological Survey of the United States. Mo. WEATHER REV. SUPPLEMENT No. 20, fig. 55, 1922.

TABLE 1.—*Frequency, amount and duration of precipitation with reference to wind direction and season.*

Direction.	Number of times precipitation occurred.	Percentage of observations for all directions.	Average amount of precipitation.	Average duration of precipitation.
SPRING.			*Inches.*	*Hours.*
N	26	11	0.29	7
NE	55	23	0.36	8
E	29	12	0.32	8
SE	46	19	0.35	6
S	22	9	0.22	4
SW	13	5	0.07	2
W	10	4	0.23	2
NW	42	17	0.25	4
SUMMER.				
N	22	7	0.19	3
NE	54	19	0.36	3
E	34	12	0.41	3
SE	57	20	0.39	4
S	26	9	0.23	3
SW	38	13	0.20	2
W	14	5	0.19	1
NW	45	15	0.22	2
AUTUMN.				
N	21	12	0.28	11
NE	44	25	0.40	9
E	15	8	0.20	6
SE	26	14	0.22	6
S	23	13	0.24	6
SW	16	9	0.22	3
W	3	2	0.05	1
NW	30	17	0.17	4
WINTER.				
N	23	20	0.11	9
NE	32	28	0.22	11
E	11	9	0.21	7
SE	17	15	0.13	9
S	9	8	0.07	6
SW	4	3	0.04	5
W	1	1	0.04	3
NW	19	16	0.15	9